ELECTRICAL INSTALLATIONS

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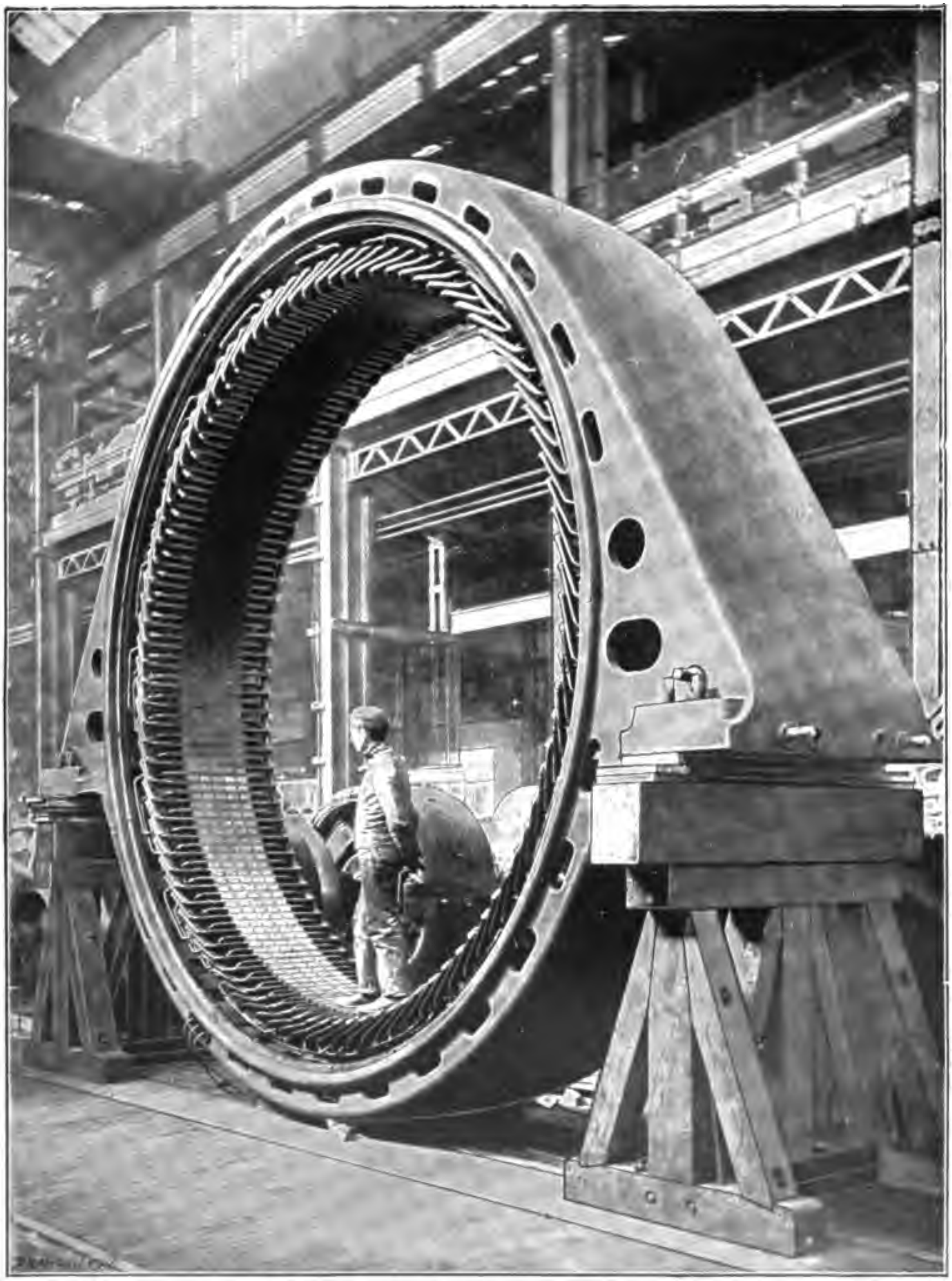

ARMATURE OF A TWO-PHASE ALTERNATING FLYWHEEL GENERATOR. WESTINGHOUSE

ELECTRICAL INSTALLATIONS

OF

ELECTRIC LIGHT, POWER, TRACTION AND INDUSTRIAL ELECTRICAL MACHINERY

BY

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IN FOUR VOLS.

WITH NUMEROUS DIAGRAMS AND ILLUSTRATIONS

VOL. I.—THE ELECTRICAL CIRCUIT, MEASUREMENT, ELEMENTS OF MOTORS, DYNAMOS, ELECTROLYSIS

LONDON: THE CAXTON PUBLISHING CO.

1902

Printed by BALLANTYNE, HANSON & Co.
At the Ballantyne Press

PREFACE TO VOL. I

THE main object of this book is to describe in detail, first, the scientific principles underlying the practice in electrical engineering, and secondly, the actual practice in the various branches of electrical engineering. The first volume is necessarily elementary and general in treatment. No attempt has been made to dip into the abstract sciences of electricity and magnetism further than to reach results and principles actually practised. For instance, it is not necessary for a practical man engaged in engineering to work out curves of permeability for iron; it is sufficient for him to have a table of exciting power required per inch length of iron to be magnetised to any degree within which he works. It is more important for the practical man to know how to apply the facts and figures obtained by the pure scientist than to know how they are obtained. Hence, this first volume refers to the methods for using ascertained figures, or values, without any pretence at explaining how such values have been arrived at. Similarly, it is not necessary for the practical engineer to treat magnets as the scientific magnetician does. He has only to deal with ampere-turns and reluctance and the resulting magnetic flux in a magnetic circuit. At the same time the student should as far as possible study the more abstract and purely scientific basis of the division of the subject upon which he may wish to become a specialist.

It seemed to the author better to direct attention to the facts, figures, values, and special devices of practical importance, assuming only an elementary knowledge of magnetism and electricity and arithmetic on the part of the reader; and to recommend experiments as an aid to understanding the common units of measurement and their value, also the use of ammeters and voltmeters, not as mere indicators on a switchboard, but as instruments of research whereby one can examine an electrical installation or circuit by Ohm's laws. The study of static electricity is only of value from the dielectric point of view, and has so been treated.

Electrolysis is becoming of great importance, and is the one division of electrical engineering which has from Faraday's time down to this day been treated in a thoroughly practical manner. In this volume only the leading principles have been referred to, recom-

mending experiments again in every case, with exact measurement by ammeter and voltmeter.

Practical engineers had to find out the principles of the magnetic circuit. Twenty-five years ago the designing of magnets was mere guesswork, or left to the "designing eye." I have not entered into this part of the subject from the "free magnetism" and "single magnetic pole" point of view, but only from the "magnetic circuit" theory; for in practice the engineer has rarely to study a magnetic problem from any other standpoint.

The scientific student should go back to the early principles and master the old science, more especially as the correlation of physical units cannot be understood without a knowledge of the early theories.

The succeeding volumes of this work deal in detail with actual practice in the great divisions of the subject.

The English system of magnetic units has been used, but in the full treatment of dynamos and motors both that and C.G.S. unit system shall be illustrated.

Thanks are due to the manufacturers of the various appliances illustrated, for assistance with blocks and information kindly supplied.

RANKIN KENNEDY.

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INTRODUCTORY

ELECTRICIANS are often questioned by intelligent people as to "What is electricity?"—a question which cannot be answered. But the electrician is not alone in his inability to define the very thing he is most concerned about. Everybody uses heat and light; yet ask any one, educated or otherwise, What is heat? what is light? nine out of ten people would be compelled to say they don't know. The tenth might be able to explain that we had only a theory as to what they were, but no exact proof as to their real nature. But while we cannot know what these natural forces really are, that does not prevent us from finding out how to control them and how to apply them profitably to our requirements.

The electrical engineer's business is to learn and apply the properties of electricity, the laws of its actions, what it can accomplish, how best to apply it, control it, and obtain its power. This he can do without knowing exactly what it is.

From all that is known about electricity, we can treat it as a fluid, very much like water in its behaviour. Unlike water, however, it cannot be felt, seen, or weighed, yet we can measure it accurately by its effects.

The best way to get an insight into the laws of electricity is to see its great similarity to water power. The most of people know a great deal about water, its quantity, pressure, and flow through pipes; hence by analogy we may teach a great deal relating to electricity.

In all electrical installations we have a source of electric pressure. The source may be a galvanic battery or a dynamo electric machine. In public supplies of electricity each consumer is supplied through two terminals connected up to the street mains. For all practical purposes these two terminals are to the consumer his source of electrical energy or pressure.

In order to grasp the meaning of a "circuit," and also to start out with a clear idea as to what part electricity plays in a "circuit,"

the following analogy in the shape of a water installation may be studied with profit.

Water will flow from one place to another only under pressure. The place from which it flows must be higher than the place it flows towards, the pressure being greater the greater the height; and it may be forced from a lower to a higher position by a superior pressure applied by a pump or water lifter, and the water may be caused to transmit power to water engines, turbines, and other engines, at a distance.

Fig. 1 is a diagram of a water-power installation, wherein water is continually used over and over again for carrying the power of an engine to small turbines used by distant consumers of power. In the figure, E is the engine, driving a pulley on a centrifugal pump P, designed to lift water from reservoir R to reservoir R 1. From the higher reservoir R 1 a supply pipe A goes out to which each consumer is connected by branch pipes for driving motors M M M M M M. Each consumer has a controlling tap S S S for turning on and off the water, and a meter A for measuring his consumption of power. All the water, after passing the water motors, flows into the return main pipe B, and thence back to reservoir R to be lifted up again for supply. In the main supply A we place a large valve or tap and a meter to measure the water going out, and a pressure gauge V to measure the pressure is connected at the low level.

Now let us consider this perfectly practicable installation for supply of power by water; it resembles an electrical installation very closely.

First, then, we have a source of power consuming coal or gas, to keep it going. The power is expended in lifting water from a low to a higher level.

The water in this way may be lifted 100 feet above the level of the return pipe B, thereby producing a pressure available at the water motors of, say, 40 lbs. per square inch. We may suppose each motor to take 100 gallons of water per minute, to do its work at that pressure. Five motors each taking that quantity would give a total quantity of water to be lifted per minute as equal to 500 gallons to a height of 100 feet, to keep all going.

Now a gallon of water weighs 10 lbs., so that we have $10 \times 500 \times 100 = 500{,}000$ foot-lbs. of work to be done by the engine every minute, or 5000 lbs. of water lifted 100 feet per minute.

A horse-power is equal to 33,000 foot lbs., hence $\frac{500{,}000}{33{,}000} =$ a little over 15 horse-power. This for lifting the water alone: in order to overcome friction of the machinery and have plenty of power, the engine would require to be at least 20 horse-power. Now let us

Water and Electric Circuits

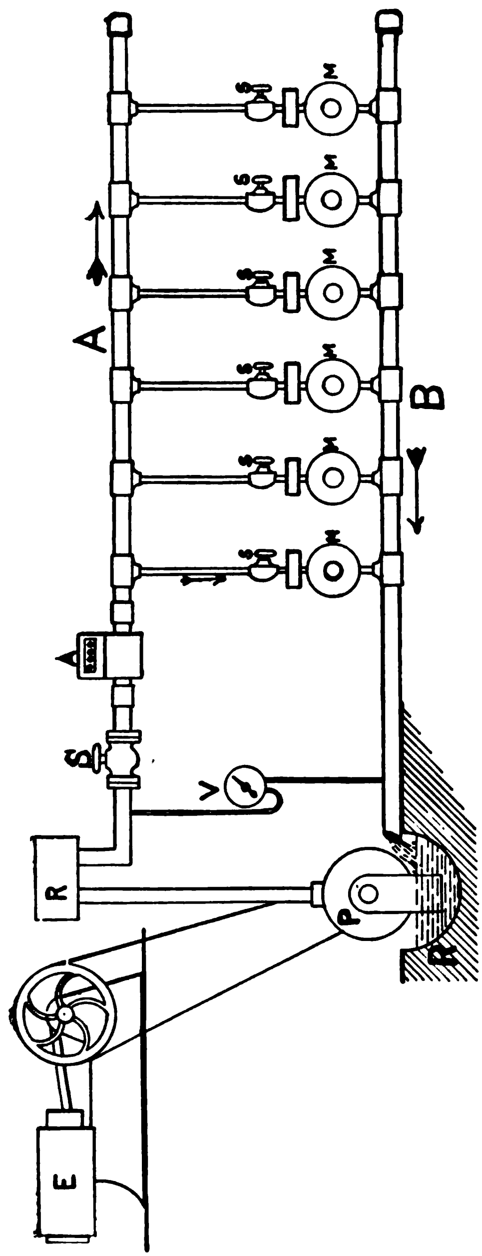


Fig. 1.—Hydraulic Parallel System

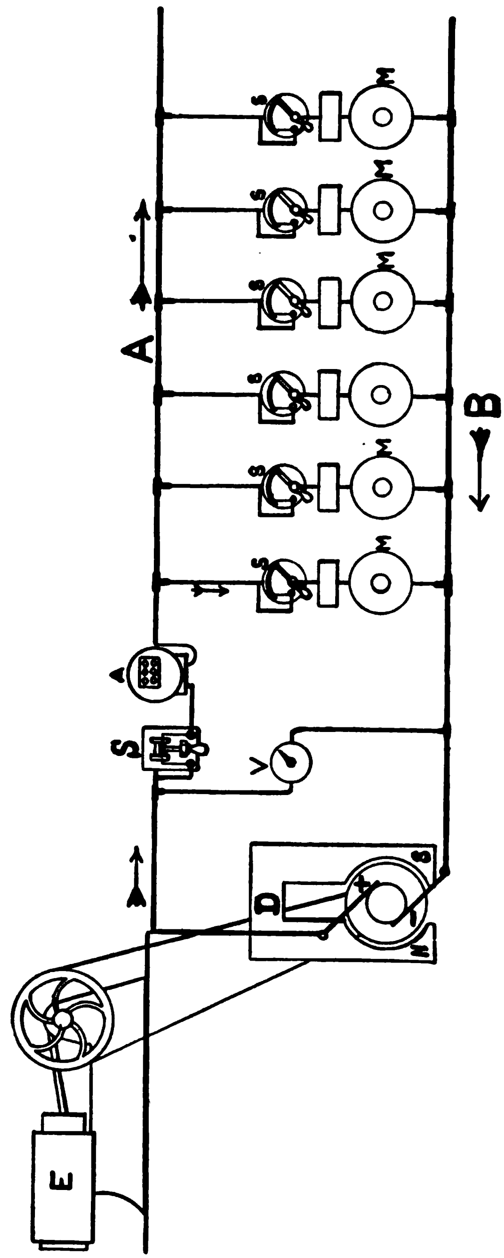


Fig. 2.—Electrical Parallel System

again look at this installation. The first thing to be noted is that we must have pressure on the water at the motors; secondly, we must have a "quantity" of water. Now the important point to see is, that, in this installation, which might be called a hydraulic installation or water installation, we *neither generate nor consume* water. The water simply *carries* the power: all the water which enters a motor flows back again to be lifted up. What we do use is the pressure of the water, and the power of the engine is used to maintain this pressure. Looked at in this simple, natural manner, the water is only a carrier of the power from the engine to the water motor.

Another important point in this installation is the fact that the power required to be expended by the engine is always proportional to the number of motors in use at any time. Let us suppose first that all the consumers shut off their taps. It is evident there shall very soon be no water in the lower reservoir to be lifted up, and hence the engine will have only the idle pulleys and pump to drive round. Then let us suppose one motor turned on, say, half power; 50 gallons per minute will then have to be lifted, and 50 gallons a minute will flow into the lower reservoir; turned full on, 100 gallons per minute will flow into the lower reservoir, and with, say, three motors full on, 300 gallons per minute. The amount of water lifted is regulated by the number of motors working at any time.

It is well known that pipes have a certain resistance to the flow of water. This resistance will, of course, play a part in a water installation. If the pipes are long and narrow, the quantity of water forced through them will be less than through wide, short pipes. The pressure on the motors will be reduced by the friction or resistance of the pipes.

And finally, we must take into consideration the pressure, and use pipes, valves, taps, meters, and joints of sufficient strength to keep the water safely locked up.

In an electrical installation we have the same effects and principles. In the case of the water the *circuit* is formed of the pressure raiser (water lifter) through the main pipe A, through the fall pipes s s s s s s, the taps, meters, motors, and back through the return pipe B, thus making a complete circular tour for the water. At the one point it is raised in pressure, thus absorbing power; in the other part of the circuit it gives off power by falling to the lower position again.

A circuit, then, may be defined as a combination of a pressure generator (inasmuch as it lifts the water to produce pressure), a pair of mains, one to carry the pressure and the other as a return main, the circuit being completed by motors or other devices using pressure.

It will be obvious in the water installation that the main return

pipe might be left out and the water run back through a trench or drain in the earth. The installation would then be said to have an earthed return.

Now suppose we made a large hole in the pressure main, the water would escape from this hole and return without driving the motors, taking a short and easy path home to the lifter. If the hole were large enough the water would flow out at great speed, leaving none for the motors, and it would flow at such a rate back into the pump that it might overpower the engine. In electrical language we would call this a "short circuit," the flow taking place through a short easy circuit instead of through the longer working circuit.

Generally considered, we see that in order to have a fairly efficient water installation, the pressure raiser should be driven by an economical engine, and should in itself have little friction. The pipes, taps, and valves, and instruments such as meters, should offer small resistance to the flow of water, so that the pressure available should be as high as possible at the motors.

Reverting to the electrical installation to see how it agrees with the ideas obtained from the study of the hydraulic analogy.

Referring to Fig 2. The engine E drives a dynamo electric machine D, a machine which raises the electricity from a low to a high pressure. From one terminal of the dynamo a main conductor A, and from the other a main conductor B, the dynamo raises to one of them, say A, electricity to a higher pressure than that in B; in the water case the pressure in A was equal to 100 feet of water above B, corresponding to nearly 40 lbs. per square inch of pressure. Now in electricity we cannot measure by square inches or by lbs., but we measure the electrical pressure by *volts*, on a gauge called a voltmeter. Volt in electricity is identical with lb. pressure, or head of water. Raising electricity from a low voltage to a higher is equivalent to lifting water from a low level to a higher level.

Then, again, each motor took so many gallons of water at the given pressure to do its work; similarly, the electric motors M M M M M M will take a certain quantity of electricity to do their work.

The water motors took 100 gallons per minute, or 1.6̇6 gallons per second.

Electricity cannot be measured in gallons, but we can measure it in "coloumbs" by a meter. The "coloumb" is in electricity equivalent to the "gallon" in water: it is a measure of quantity. One coloumb per second passing through a meter called an "ampere meter" would indicate "1 ampere," as an ampere is a rate of flow equal to 1 coloumb per second.

The coloumb is not much used as a measure, the rate of flow indicated by an ampere meter being used, it being the custom to say that "a lamp or a motor takes 5, 7, or 10 amperes." The ampere is

a measure of rate of flow, for which we have no corresponding mechanical name nearer than "pounds per second."

The hydraulic engineer calculates his power by "pounds per second" multiplied by "feet lifted." The electrician uses amperes multiplied by volts. The amperes being so much quantity of electricity per second, and the volts the height to which it is raised in pressure.

We have hitherto applied the arguments to motors in the circuit driven by pressure, but the same applies to lamps or other devices. In an electric lamp, electricity is not consumed as oil or gas is consumed or used up in a lamp.

The electricity is forced through the lamps by the pressure put upon it by the dynamo, and in passing through the filament of an incandescent lamp or across an arc in an arc lamp, it produces heat sufficient to raise the temperature to the incandescent point. Losing its pressure in doing so, the electricity, as before, returns to the negative or return main, and thence back to the dynamo.

In comparing the two systems, we note that in both we deal with something circulated through a complete circuit, the circulation being kept up by a prime mover forcing the water or the electricity through the circuit, and that in both the actual power or effects obtained are due to the pressure and the quantity of that which is circulated. The fluid carries the power throughout the circuit, but is not itself consumed or used up.

In a hydraulic system we commence with a certain large quantity of water put into the system, and then pump it up to the higher level to get the pressure required.

But in an electrical system we do not require to put electricity to start with into the system. The electricity exists in the copper wire or bars in the dynamo, and in all the conductors in the circuit, and it is ready to be set in motion by any suitable means. This is the conception with which it is necessary to commence with.

It can be set in motion by chemical action, as in a battery consuming zinc; or by heat, as in a thermo-pile; or by magnetism and motion, as in a dynamo.

In this treatise it is not necessary to treat minutely these means for driving electricity through a circuit; but to fix a few fundamental ideas, it may be interesting to consider a few elementary experiments, and the facts revealed by them.

If we take a copper wire coil, as in Fig. 3, with two ends connected to a fine galvanometer, we shall find that if a magnet pole is poked into the ring, a current of electricity is indicated by the deflection of the galvanometer needle. If it is withdrawn, a reverse current is produced, thus showing that something in the copper ring has been set in motion by the movement of the magnet. Of course,

fixing the magnet and moving the ring would also produce the same effect.

But to study this further we must investigate more particularly to find how the magnet acts to set the electricity in motion.

Magnetism also acts in a complete circuit. Electricians are accustomed to represent the magnetic flow by lines indicating the flow through a magnet and through the air or other paths along which it flows. This is shown by the curved lines dotted in Fig. 3 around and through the straight bar magnet N S; at each end of the magnet these lines stand out at right angles nearly, like the bristles of a brush. Thus in moving the magnet pole out or into the ring, the ring is said to be cut by the magnetic lines, and this cutting across of a conductor by magnetic lines sets up the flow of electricity in the circuit. Now if we tried the experiment by moving the coil over the middle of the magnet, we would find no effect, because in that position the magnetic lines are parallel with the magnet, so that moving the magnet or the coil in that position does not cause a cutting of the magnetic lines. The lines must be at right angles to effect a cutting movement.

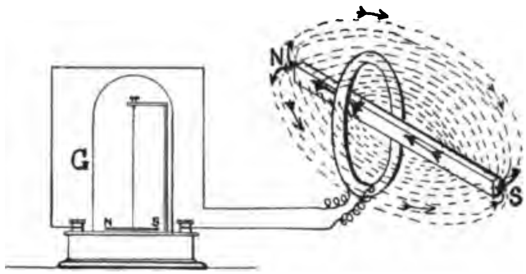


FIG. 3

Electric pressure is set up in any circuit in which a conductor cuts lines of magnetism at right angles to the conductor.

A steel magnet permanently magnetised may be used for the experiment, but more instructive experiments may be made with a horse-shoe soft iron electro-magnet. An electro-magnet consists of an iron core magnetised by a coil or coils of wire carrying an electric current. And the effects are more easily seen if we use a coil of wire of many turns: the best magnet for our purpose would be made up of thin soft iron stampings riveted together by four small rivets, and the corners rounded off.

In the electrical installation we may have a common pressure, to which the electricity is raised, say, 220 volts, and 10 amperes quantity of electricity for each motor. Thus we have for five motors 50 amperes as the quantity of electricity coming from the motors to be lifted up to 220 volts.

$$\text{Now } \frac{220 \times 50}{746} = 14.75 \text{ horse-power.}$$

In the case of water foot-lbs. are used, 550 foot-lbs. per second being a horse-power. In the electrical case volt-ampere—that is,

amperes multiplied by volts—is used. Electricians call the product of volts multiplied by amperes "Watts," and 746 watts equal one horse-power. So that in the case of foot-lbs. we reduce to horse-power by dividing by 550; and in the case of volt-amperes we divide watts by 746. The main point is to see that although the names differ and the figures are different, the process is the same for both mechanical power and electrical.

In deciding upon units for calculations, it would have been quite easy to have made them of such a value that volts were equivalent to feet and amperes to pounds, and watts or volt-amperes equal to 550 per horse-power. But the electrical units have been made to fit into the Centimetre Gramme-Second or C.G.S. system, while mechanical and hydraulic units are in this country the pound and foot, instead of the gramme and centimetre.

Again, in both systems we may deliver the power under different conditions. We may use a very high lift in the water system, say 1000 feet instead of 100 feet; and similarly we may use 10,000 volts instead of 220 in our electrical system. In the water system every pound of water would then carry $1000 \times 1 = 1000$ foot-lbs. instead of 100 foot-lbs. And in the electric system every ampere would carry 10,000 volt-amperes, or Watts.

We may therefore get the same amount of power at a large pressure with small currents of either water or electricity; or, *vice versâ*, we may use small pressures and large currents.

Thus we may use 100 feet of water pressure and 1000 lbs. of water per second to get 100,000 foot-lbs. per second, and 100 volts and 1000 amperes to get 100,000 volt-amperes or watts. Or we may employ 1000 feet of water pressure and 100 lbs. of water per second to get the same water power as before = 100,000 foot-lbs., and 1000 volts and 100 amperes to get 100,000 watts.

Pressure alone, pounds of water, volts alone, and amperes alone, signify nothing. A jet of water forced through the eye of a fine needle by tens of thousands of pounds per square inch of pressure would have very little power to drive a mill; and similarly, a very small current of electricity at even immense pressure has but little power.

Again, a vast quantity of water falling one or two feet has very little power. With a fall of one foot 33,000 lbs. of water, or nearly 15 tons per minute, would be required to get 1 horse-power.

And so with electricity, with one volt of pressure, 746 amperes would be required for driving a one-horse motor—a quantity of current which would require a copper rod of one inch diameter to carry it.

It will be clear that the use of high pressure would save considerable cost in conductors, whether for conducting the water current or

the electric current, for the higher the pressure the less the fluid required to do the work.

On the other hand, there is a limit to the height of the pressure. In the case of water, the valves, taps, meters, motors, and pipes cannot be made to withstand any pressure. They become liable to burst, and become unworkable above certain pressures. Similarly with electricity. At high pressures it is apt to burst through the insulation, and to leak through switches and burn up the motors; so that, while the electrical engineer strives to use high pressures, he must take every care that his apparatus is made to withstand them.

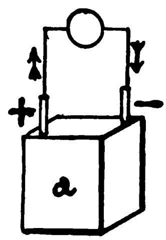


FIG. 4

In both hydraulic and electric installations, as in Figs. 1 and 2, the motors or other consuming devices are shown connected to the supply and return mains independently, each with a pair of connections of its own. This is said to be a "parallel system," because they appear "in parallel."

Referring to the illustrations, five systems of connecting lamps to a source of electric pressure are diagrammatically shown, a battery being used for the supply. In Fig. 4 one lamp is shown connected across the two poles + and −. There is no other way of connecting it up; but immediately we contemplate coupling on more than one lamp of same size we see that there is more than one way to do it.

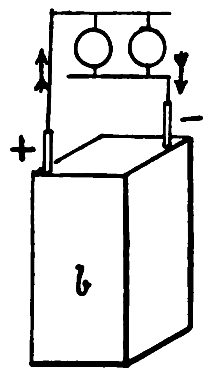


FIG. 5

We may put them in as in Fig. 5, *i.e.* in parallel, or we may put them in as in Fig. 6, in series.

If we had a number of lamps, we might put them into a circuit, as in Fig. 7—two and two, or three and three, in two parallels.

And we might use the earth as a return, as in Fig. 8.

Battery *b* would require to be twice as big as battery *a*, for it has twice the work to do, twice the quantity of electricity to supply. Battery *c c* would be same size as *a*, but would require to give twice the pressure — that is, supply same current of electricity through two lamps in series. It will require twice the pressure to send the current through two lamps in series that it does to send current through one lamp in the same quantity.

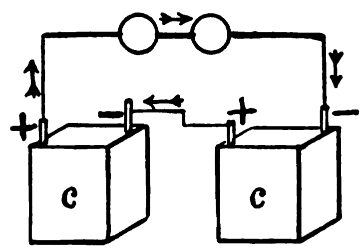


FIG. 6

Battery *d d* would require to be capable of giving the same quantity of current as battery *b*, for the lamps are two in parallel as in battery *b*, and would have to give twice the pressure of battery *b*, for there are two series of lamps.

The pressure required is proportional to the number in series.

The quantity required is proportional to the number of lamps in parallel.

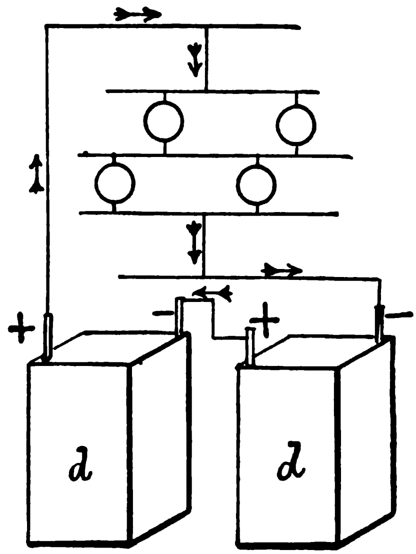


FIG 7.

Fig. 8 is typical of earthed systems. For instance, in a steel ship we may use the ship for return of current to the dynamo, and in electric tramways or railways we may use the rails as a return path.

The series system of connecting consuming devices is applied to arc lamp work scattered over long distances, as it requires only one wire from lamp to lamp to carry current sufficient in quantity for one lamp only, as the same current passes through all the series.

It is useful also in electrical chemical processes, and other applications where each lamp or chemical vat requires only a low pressure but a fairly large current. A high-pressure dynamo can be used with a single wire from lamp to lamp, and thereby save copper. It has some drawbacks, however, as we shall find later on.

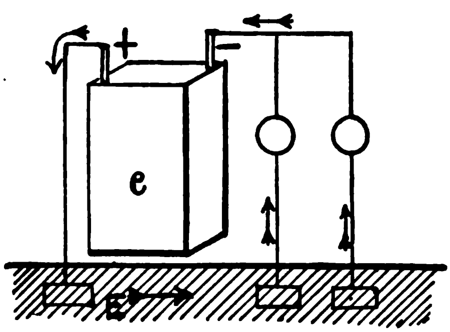


FIG. 8

Fig. 9 is typical of the three-wire system of electrical circuits so commonly used in public supplies of electricity. Here we have two sources of electric pressure, *f f*, joined up in series, as in Figs. 6 and 7, in order to add their pressure together. It must be noted that to add pressures the sources must be joined $+ \underbrace{- \quad +} \ \underbrace{- \quad +} \ -$.

In Fig. 9 there are three wires, one from the + pole and one from the — pole; these are called the "outer wires" or, for short, the "outers." A third wire is taken from the junction of the two cells *f f*, where the — pole of the one joins the + pole of the other cell.

By this arrangement a considerable saving in copper is claimed in the conductors. For if the number of lamps in the one circuit equals the number of lamps in the other, no current would flow in the third wire from the junction of the cells; and if the numbers were unequal, only current for the difference would flow from the junction. And as in practice the circuits are always nearly balanced, the third wire, forming a common return path for both outers, requires to carry only a small current, it may be made of small section. This is the advantage in the three-wire system over the multiple series circuits shown in Fig. 7, wherein no connection is made to the junction of the two cells.

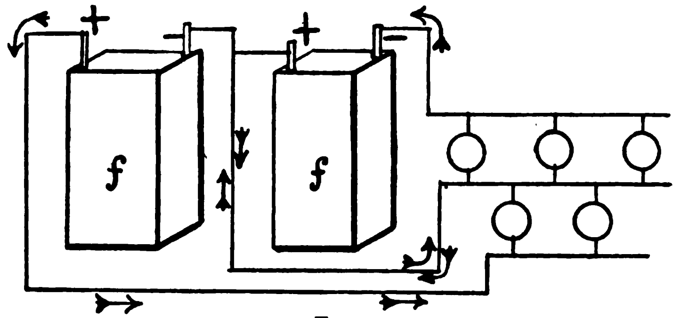


FIG. 9

Simple experiments can be made with cells to familiarise the student with these circuits; experiments to be described in next chapter.

The practical systems of electrical circuits are usually represented by diagrams, such as Figs. 2, 10, 11, 12, 14.

In Fig. 10 the series system is depicted. D is a dynamo electric machine, sometimes called simply a "dynamo." The terminals are represented by lines + and −. From the positive terminal a conductor proceeds to a meter M, to indicate the quantity of electricity flowing, thence to a main switch, by means of which the circuit can be opened or closed, *i.e.* electricity shut off or turned on.

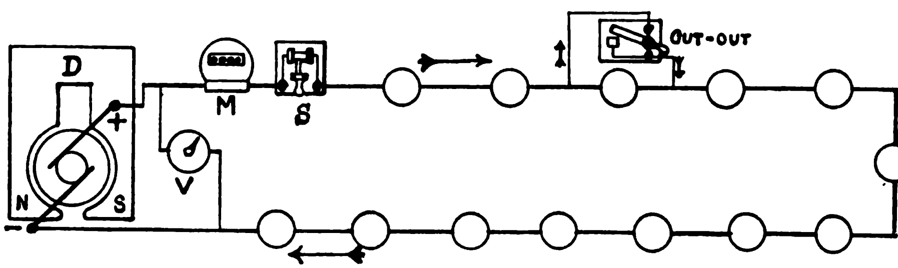


FIG. 10.—Series System

The lamps or motors are represented by circles, the current by arrows, showing it flowing from one to the other all round a series.

It will be obvious that if at any point in the series the circuit is opened or broken the whole supply is cut off, and all the lamps would go out. So that in series systems, when a motor or lamp is to be put off, a bye-pass is provided, by a switch actuated either automatically or by hand, and called a series cut-out. This is shown at one of the lamps in the series; the current can pass by the cut-out instead of through the lamp. V is a voltmeter to indicate the electric pressure maintained by the dynamo. A series circuit must work under high pressure, for each lamp adds its resistance against the pressure. It will take ten times the pressure to send the same current in amperes through ten lamps that it does to send it through one lamp. Hence, suppose one lamp took 60 volts pressure to get 5 amperes current through it, ten lamps in series would require 600 volts. We thus see that in a series system we must vary the pressure according to the number of lamps in series. And the

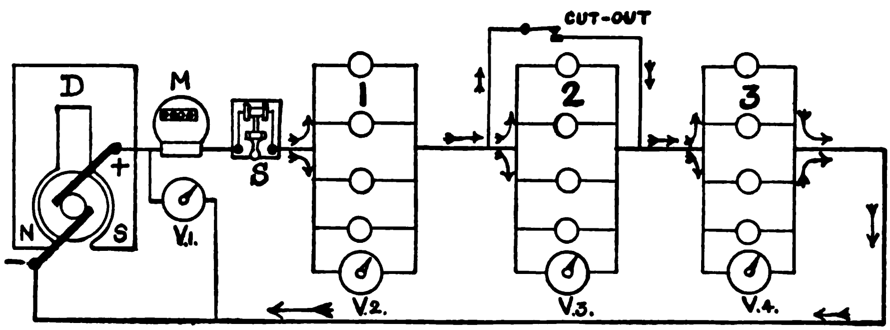


FIG. 11.—Series-Parallel System

current or quantity of electricity flowing must be the same whatever the number of lamps or motors may be in the series.

In a parallel system the volts or pressure is constant, and all motors, lamps, and other things connected thereto must be made for that constant pressure. The usual pressures in practice supplied to consumers are from 200 to 250 volts. And the current or quantity flowing at any time depends on the number of lamps and motors connected and working.

Fig. 11 is the modified series system, whereby groups in parallel are connected in series. The pressure and current in such a system must both be kept up constant, unless a whole group is cut off at a time. V1, V2, V3, V4 are pressure gauges, so-called voltmeters. We will suppose the lamps are 50 volt lamps, and as there are three series we will require $50 \times 3 = 150$ volts, to drive current through the three groups in series. V1 being connected across the mains would indicate the full pressure, 150 volts; V2, V3, V4 would each indicate 50 volts.

We could cast out, say, group 2 by a short-circuiting switch, in which case V1 would require to be reduced to 100 volts.

Fig. 12 represents the most commonly used circuit in large installations. It is an improvement upon the series and parallel systems, using two dynamos D D in series and two circuits also in series with each other. At F F are shown two installations, connected to a three-wire system, through main fuses and switches. The aim of the engineer is to connect the consumers on both sides of the middle wire so that the supply is about balanced equally, so that the middle wire may be of small section, carrying only the quantity of current required by the difference shown in the outer wires. Thus if we read on meter M 350 amperes and on M1 400 amperes, then an ammeter on the middle wire would indicate 50 amperes, the difference carried by that wire.

We could put on another two dynamos and another pair of wires, and so have a five - wire

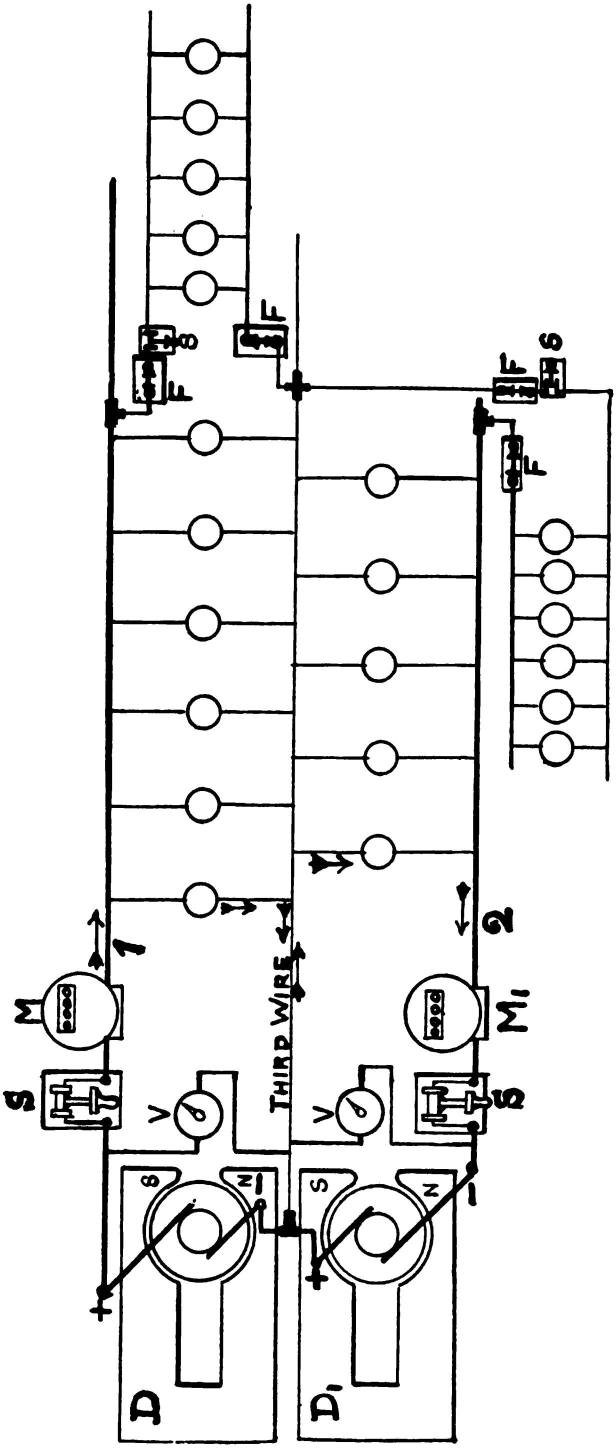


Fig. 12.—Three-Wire System

system, as shown in diagram, Fig. 13. This system was actually worked in Manchester on a large scale, but its intricate complications and lack of practical advantages has prevented its use elsewhere. It is an example of a theoretical principle being carried beyond the range of practicability.

The parallel-earthed system, so common in tramway and ship circuits, is represented in Fig. 14. It explains itself. It can also be used as a three-wire system, making the earthed return the middle wire connection.

There are other more complicated circuits designed to transmit electrical energy at very high pressures, and to feed through transformers into low-pressure circuits. And finally, there are the "wireless" circuits, so called, at present used only for telegraphy. In these circuits there are wires to a considerable extent—long vertical wires insulated from everything above the instruments, but connected to earth below and through the instruments. These circuits will be described later on.

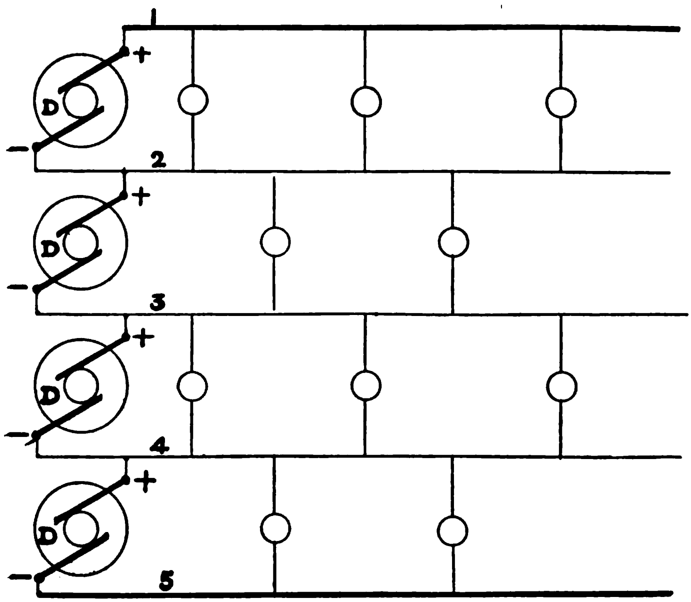


FIG. 13.—Five-Wire System

In all circuits for supplying or applying electricity we have the pressure generator or "dynamo," a machine which is simply an electricity pump, pumping up electricity from a low to a high pressure. There is no generation of electricity in the "generator." To the outlet terminal of the dynamo marked + we attach a conductor leading to the consuming devices and another conductor marked − leading back to the − terminal, so that the electricity is pumped through the consuming devices continually round and round the circuit.

To carry the current of electricity the wires are made of copper, because it offers less resistance to the flow than other metals, and it is made of section large enough to reduce the loss by resistance to a minimum. This loss due to resistance is equal

to the current multiplied by the resistance represented by the formulæ.

Drop in pressure = C × R (current × resistance), where C is current in amperes and R is a unit of resistance.

Resistance of conductors is a very important factor in circuits, and must be thoroughly understood.

Then the electricity under pressure in the wires tends to leak, and does leak away through anything which makes contact with them.

The quantity of electricity which passes through any body depends, first, on the pressure or "voltage"; and secondly, on the resistance of the body. Substances which allow a large quantity to pass through at low pressures are good conductors or low resisters. Practically, copper is the most important conductor for conductivity purposes, due to its small resistance. Other metals are of importance, due to their high resistance in cases where resistances are required, designed to regulate the flow of current.

We thus have two classes of metallic resistances: low resistance metals for carrying current at small loss, and high resistance metals for opposing the pressure and cutting down the flow of current.

Then there are substances whose resistances are very high, called insulators. All wires carrying electricity under pressure must be carried upon or covered by insulators. It is a familiar sight to see the telegraph lines carried on stoneware or glass insulators on poles; these insulators offer a very high resistance to the pressure, hence very little electricity leaks through them. Air is a very high resistance insulator, so that electricity does not readily escape or leak from a wire or conductor surrounded by air.

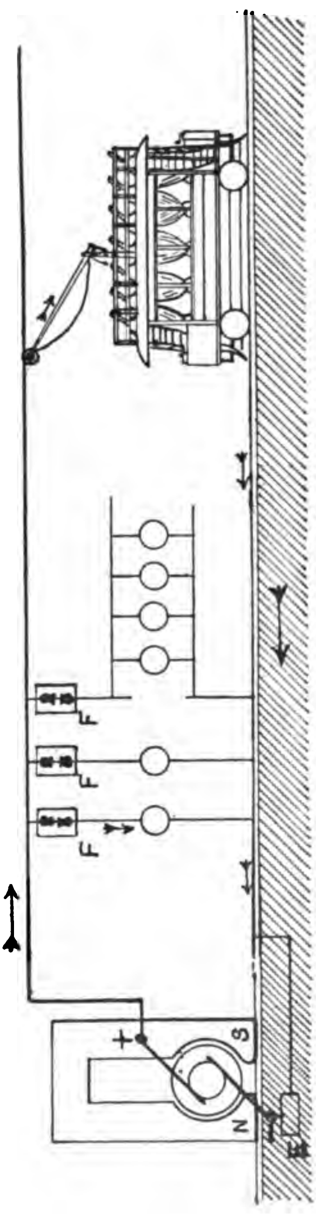


FIG. 14.—Parallel-Earthed System

Then, again, there are intermediate substances which have a middle value, neither good conductors nor good insulators, of no

use to the electrician as a rule. Among them, however, are carbon, water, damp earth, and high resistance metals of considerable value.

Then another class of substances through which electricity passes are called "electrolytes," consisting of chemical solutions, fused salts, and heated compound bodies, in which chemical actions are set up by the electric current.

List of Conductors

Good Conductors.—Copper, bronze, silver, platinum, brass.

Good Resistance.—German silver, iron, carbon, water, rheostene, manganin.

Good Insulators.—Ebonite, glass, rubber, gutta-percha, oils, dry cotton waterproofed, jute waterproofed, bitumen, mica, micanite, shellac, air, slate, marble, vulcanised fibre, dry wood.

There is no such thing as a perfect insulator, nor is there a perfect conductor.

Every conductor resists the passage of electricity, so that lost energy equal to $C^2 R$ can be counted upon in every case.

And in the case of insulators, also, the quantity of electricity which passes through them is always equal to the pressure divided by the resistance. If we call the pressure E, and the resistance R, the current which escapes through the resistance is equal to $\frac{E}{R}$, which gives the current C passing.

Practically, however, the loss in copper conductors is exceedingly small when they are properly proportioned to the current and pressure.

And the same with insulators. A wire covered with gutta-percha as an insulator leaks practically an insignificant amount even when over 3000 miles long.

A conductor's resistance is directly proportional to its length, inversely proportional to its cross section, and in metals increases with temperature. In carbon and most liquids the resistance decreases with temperature.

Insulators follow the same general laws, but require careful study into a strained condition set up in them, whereby they are apt to break down suddenly and allow a discharge to take place through them.

The electric pressure may be increased gradually upon an insulator until it suddenly gives way, and is pierced or ruptured. In this way a hole may be bored through a sheet of glass; and so a flash of lightning is produced by an enormous electric pressure between the clouds and the earth suddenly overpowering the air resistance, and piercing it in a zig-zag path, followed by the thunder

produced by the heat generated along the path of rupture expanding the air.

We shall have occasion to consider this tendency to burst through insulation in many of the apparatus in practical use, and to study the practical engineer's devices for preventing damage thereby to his wires, switches, lamps, and other things.

Electricity, again, resembles water in that it has momentum. If we allow water under pressure to flow out of a pipe with a tap on the end of it, and suddenly close the tap, the water will hammer violently on the pipe, and probably burst it, because it cannot be suddenly stopped in its motion without giving up the energy which set it in motion. In fact, there are water-pumps which act on this very principle, called "hydraulic rams." The water is allowed to flow freely, and is then stopped by a valve, but its momentum or energy of motion carries some of it on through another valve into a receiver, where it compresses air, the expansion of which forces it up to a higher level or pressure. Similarly, a flowing electric current cannot be cut off or stopped without a rise in pressure, and the quicker it is cut off the higher the rise in pressure.

Some circuits require special devices for cutting off current gradually instead of suddenly, to prevent damage to the insulation and to devices in the circuit.

There is, however, one great feature of difference between water and electricity. Water can be pumped up into a reservoir or storage tank, and used at any time to give back its power by falling through a turbine.

Electricity cannot be stored; the storage battery does not store electricity, but only stores energy carried into it by the electricity, and this energy is available for driving electricity again through a circuit.

The accumulator or storage battery is a converter only. It, in receiving its charge, absorbs the pressure of the current in forming chemical compounds, and these substances produce an electrical pressure again capable of application to another circuit. The electrical energy is converted into chemical energy, and again converted into electrical energy when desired, the two conversions resulting in a loss of about 25 per cent. of the original energy. In all electrical installations the great drawback is this want of storage. An efficient storage system would immensely reduce the cost of electric supply. The demand for lighting purposes comes on only for a few hours per day, and is very heavy for that short time. Hence the generating plant requires to be capable of meeting this great demand, and is idle for the greater part of the year. If storage on a large scale was possible, a small plant running all the time would provide for a large demand for a short time. Storage is at present used on a small scale principally to assist in regulating the supply.

CHAPTER II

OHM'S LAWS

To grasp the true and practical meaning of many of the terms used in describing circuits and writing about electricity, the engineer must in some way become familiar with the measurement of the quantities called volts, amperes, and other units mentioned in last chapter.

We referred to volts or pressure, and amperes, as indicating the rate of flow of electricity, also to resistance of insulators and conductors. Nothing but actual experience can teach the full meaning of these terms. And for those who cannot have access to laboratories, the only course is to make simple apparatus for themselves, or procure them, and make the experiments at home or in the workshop.

A set of experimental apparatus shall be here described suitable for the instruction of beginners in the art of electrical engineering.

The apparatus must include the following :—

1. A battery of cells for producing the electrical energy.
2. A voltmeter or pressure gauge.
3. An ammeter or current gauge.
4. An ohmmeter for measuring resistances.
5. A collection of wires, some small lamps, and connections.

There are four quantities to be dealt with by the electrical engineer—electrical pressure, electrical current, electrical energy, and resistance. Neither electrical pressure alone, nor electrical current or quantity alone, can have energy. Just as we might have water at a very high level or pressure, but only in quantity to fill a teacup, there would be very little power to be got withal the high pressure; so with electricity it is pressure and quantity which does the work, and the energy is equal to the current multiplied by the pressure, and the product (of $C \times E$) is watts, *i.e.* the unit of energy, and 746 watts are equal to 1 horse-power.

Resistance opposes the pressure, and it requires power to force the current along through any resistance. The unit of resistance by which it is measured is called the *Ohm*, in honour of the man who first taught the world the relations between pressure, resistance, and current.

The ohm standard is made usually of a wire of a certain cross section and length, and has such a resistance that it takes 1 volt

of pressure to force 1 ampere of current through it. Ten volts would force 10 amperes through it, and 100 volts 100 amperes, and so on. Any one could make a one-ohm resistance out of a wire if he had an ampere-meter and a voltmeter and electric pressure at command. Making a circuit by the wire through the ammeter, and applying, say, 10 volts pressure, the wire could be made longer or shorter until the ammeter indicated 10 amperes; the resistance must then be 1 ohm. The laws of Ohm being :—

$$(1)\quad C = \frac{E}{R}$$

$$(2)\quad R = \frac{E}{C} \quad \text{wherein} \begin{cases} C = \text{Current} \\ E = \text{Pressure} \\ R = \text{Resistance} \end{cases}$$

$$(3)\quad E = C \times R$$

In above case $R = \frac{10}{10} = 1$ ohm.

And so we could measure the resistance of any wire by finding the electrical pressure at its ends and the current flowing in it, and simply by dividing the pressure by the current; thus in the case of an incandescent lamp taking 0.6 amperes and 100 volts, we know its resistance must be $= \frac{100}{0.6} = 166$ ohms, and the power expended in it is equal to $C \times E = 0.6 \times 100$, or 60 watts. One watt is equal to 44.25 foot-lbs. per minute in mechanical equivalent.

If we know any two of the factors C, E, and R, we can always calculate the third one by above simple division and multiplication formulas.

Referring back to the illustration of the parallel circuits, it will be seen that each lamp or motor will take current simply in proportion to its resistance, and the electrician designs his lamp resistance to regulate this current; for instance, the lamp referred to above having 166 ohms resistance would be a 15 candle lamp, as these lamps usually take about 4 watts per candle power. If a lamp to take 10 amperes were required, its resistance would be, for 100 volts pressure, $R = \frac{E}{C} = \frac{100}{10} = 10$ ohms.

Voltmeters, ammeters, and ohmmeters can be bought now almost anywhere for ordinary purposes; but there is some demand for simple educational instruments, not necessarily of high accuracy, but with wide ranges and cheap to construct—in fact, such as a handy student could make, with little assistance, for himself, and in doing so learn much more than he could do from ready-made instruments.

The author has therefore designed a voltmeter, an ammeter, and a resistance measurer for such a purpose. The instruments are modifications of designs by Lord Kelvin, used in his graded tangent instruments introduced about the year 1883.

It will be assumed that the student is not in a position to com-

mand a supply of electric pressure of 200 or 250 volts for his experiments, so that the electrical energy required must come from a primary or secondary battery. The latter is the best source, if it can be readily recharged. This, however, is seldom the case; hence the primary battery will be mostly used for experiments at home by students or workmen.

Primary batteries are extensively illustrated and described in ordinary electrical text-books. Nevertheless, long as they have been in use, much as they have been learnedly treated, there is not much really instructive information widely known about them. They are, as a rule, in practice, badly abused, being generally much too small for the work to be done. By treating them rationally, they are useful experimental electrical generators. A battery consists of several cells, and each cell consists of two elements in an electrolyte.

There are many kinds of cells. Nearly all of them are made for small currents and short service. Commercial batteries are mostly too small for heavy, continuous work.

For electrical engineering work and experiments large cells are required, cells so large that the maximum current required of them does not reduce the pressure at the terminals to any appreciable amount.

Cells have resistance within themselves, called "internal resistance," so that the pressure is lost to some extent when current is driven through them in the proportion, according to Ohm's law, $E = C \times R$. If the internal resistance is 0.1 ohm and $C = 10$ amperes, then $10 \times 0.1 = 1$ volt would be lost inside the cell itself. That is to say, that if such a cell had a pressure at its terminals of 1.5 volts when no current was passing, the pressure at the terminals would drop to 0.5 volts when 10 amperes came through it. For all practical work with large currents we must use cells of low resistance; that is, the cells must be very large, with plenty of room for liquid or electrolyte.

Internal resistance figures largely in mathematical formulæ regarding cells, but in practice that resistance should be so low that it is almost negligible. In other words, the maximum current taken from any cell is governed by its internal resistance. Electrical energy supplied by primary batteries is very costly, and therefore should not be wasted in the cell or wires or connections, but should as much as possible be directed to the work to be done.

Take, for example, a cell which gives 1.5 volts and has a resistance in itself of 2 ohms, and say that we determine to be economical and work at a loss of only 10 per cent. or less, and allow a drop of 0.1 in pressure, by Ohm's law $\frac{E}{R} = C$, so that, as in this case, E, the

drop in the pressure in the cell, is to be equal to 0.1, and the given resistance in the cell is 2 ohms.

Then $\frac{0.1}{2} = 0.05$ amperes, showing that to work such a cell at a loss of about 7 per cent. in pressure, we must not take more than $\frac{1}{20}$th of an ampere from it.

A cell is required to give 5 amperes with an efficiency of 90 per cent. in pressure, what should its internal resistance be? Its pressure when no current is flowing is 1.5 volts.

$$10 \text{ per cent. drop on } 1.5 = 0.15 \text{ volts,}$$

and by Ohm's law—

$$\frac{E}{C} = R,$$

hence $$\frac{0.15}{5} = 0.03 \text{ ohms,}$$

a resistance uncommonly low among commercial batteries.

The nearest approach to such a resistance in a primary battery

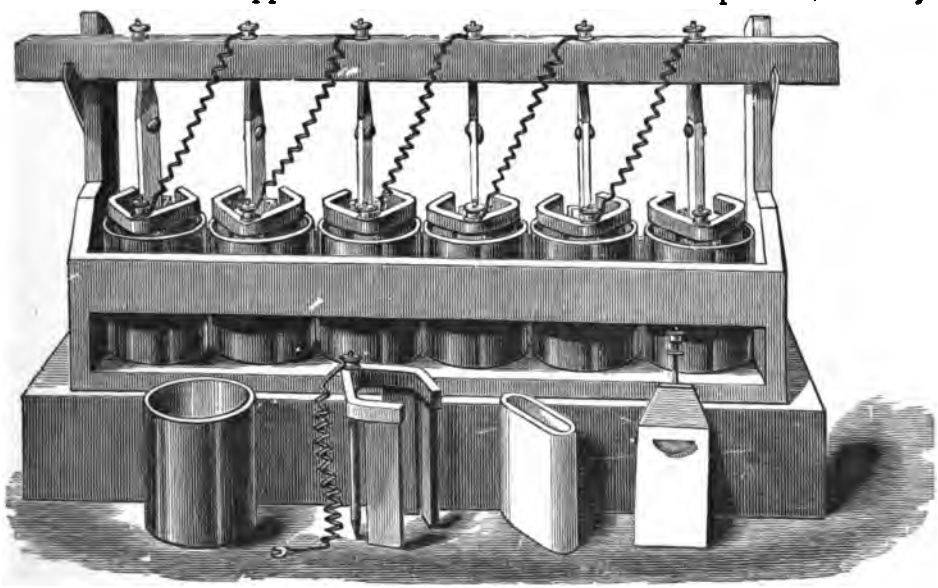


FIG. 15.—Silvertown Company's Battery of Low Resistance Cells

now on the market is in the Silvertown improved low resistance battery (Fig. 15), here illustrated and described. Its resistance is 0.05, pressure 2.08 volts, current 5 amperes, so that the drop on 5 amperes would be $5 \times 0.05 = .25$ volts, or an $\frac{1}{8}$th of the pressure—in fact, it falls to 2 volts when giving 5 amperes; this is as it should be, the result being a fairly good battery for experimentalists. It will give 5 amperes for about 20 hours, or 100 ampere-hours; or if we put it into watts, 200 watt-hours, that is $= 2$ volts $\times$ 5 amperes $\times$ 20 hours.

The rate of working is clearly per cell 5 $\times$ 2 amperes multiplied

by volts = 10 watts, and as a horse-power is equal to 746 watts, we can find the number of cells required to give 1 horse-power for 20 hours by dividing $\frac{746}{10} = 74.6$ cells; but as we cannot get half a cell, we can put it at 75 cells.

The cost is not easily calculated, for there is a good deal of labour required in charging and setting up these cells; however, the materials can be priced.

Zincs and mercury, .	75 at 3s. 3d. =	£12	3	6
Solution of crystals, .	75 at 10d. =	3	2	6
And solution, .	75 at 2d. =	0	12	6
Total material cost, . .		£15	18	6

But including labour and interest on outlay this cost might easily run to £20 for 20 horse-power hours, or £1 per hour per horse-power. This is a large price, nevertheless, for small powers up to 10 or 12 volts and 5 amperes. It is a handy and satisfactory generator, but too costly for larger powers. The same makers make Leclanche cells (Fig. 16) of 0.3 ohms internal resistance, 1.55 volts pressure; hence by Ohm's law, and allowing a drop in pressure equal to 0.155, we get $\frac{0.155}{0.3} = 0.51$, or half an ampere as a maximum current with economy.

Fig. 16.—Silvertown-Leclanche Cell

It will be thus seen that to get the same rate of work out of a battery of these cells that we get out of the other one, that is, 10 watts, we would require many cells; for we had 2 volts and 5 amperes per cell, now we have 1.5 volts and 0.5 amperes, or $1.5 \times .5 = 0.75$ watts per cell, so that to get 10 watts we want $\frac{10}{0.75} = 14$ cells (nearly). It is clear that high internal resistance and low pressure are exceedingly detrimental in cells.

The cost of the first described cell is about 10s., the last 5s.; but the 10s. cell does fourteen times the work.

A six-cell battery giving 2 volts per cell, or 12 volts and 5 amperes, may be required for the tests which every engineer should be acquainted with.

Wherever a charge can be obtained for a storage battery, that can be used at much less cost and trouble, the battery should consist of six cells, discharge rate 5 amperes a maximum.

The E.P.S. Company make a battery, here illustrated (Fig. 17),

called Q type. The whole weighs half a hundredweight. It will give about 20 ampere-hours with one charge. Fifteen volts and 4 amperes for five or six hours will be required to charge it; that means $15 \times 4 \times 5 = 300$ watt-hours for each charge. Electricity can be had at 6d. per 1000 watt-hours from public supplies, so that the cost of charge would be about 2d. for electricity. Added to this would be carriage, labour, and profit; but even if such a battery cost 2s. 6d. per charge, it would be cheap for experimental work.

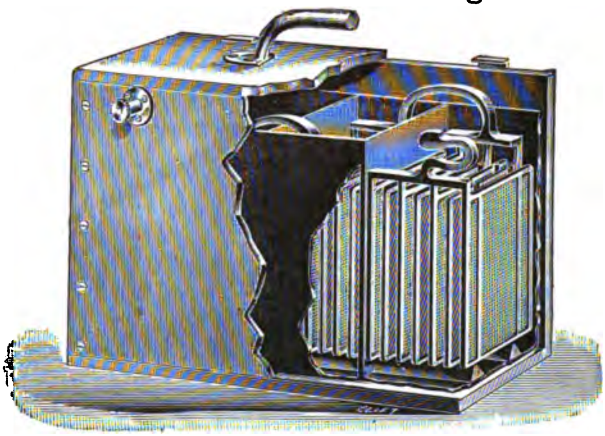


FIG. 17.—E.P.S. Company's Q Type Accumulator Battery

In London, and perhaps in other large towns, storage cells ready charged can be hired at small cost for experiments. The cost of the primary battery and the secondary battery are about the same, £3 or thereabout. The next type of cell required is for intermittent uses and small currents. For these purposes internal resistance is of little importance, though we must still notice its effects. We require cells as standards, and for tests upon resistances, and

FIG. 18.—Battery of Daniell Cells.

so on; and for the purpose it is as well to select a cell which gives as near as possible 1 volt pressure. The Daniell cell does this, and maintains it fairly constant.

The Silvertown 10 cell quantity Daniell has been selected for the purpose; it is fairly cheap, compact, and well made. Fig. 18 shows it complete in a box; Fig. 19 shows a separate cell complete. The zinc is in a porous pot surrounded by a copper cylinder; in the porous pot is a half-saturated

solution of zinc sulphate, in the outer vessel saturated copper sulphate. A handy student or workman can easily make up ten Daniell cells at small cost (see Fig. 20). The outer cell may be a copper vessel, very thin, with an inner shelf about half an inch broad all round, perforated to carry sulphate of copper crystals; such cells can easily be home made at about 1s. each for materials.

Fig. 19.—Daniell Cell.

The batteries should not be charged or set up for action until everything else required for experiments is ready for work; hence, though described first, they may be procured last of all the apparatus.

The first instrument to become acquainted with is a voltmeter or pressure gauge. Many are in the market, admirable instruments for everyday use; but few can be found fitted for the experimental table.

There is a great deal too much lacquered brass, bevelled glass, green tape, paint and powder make up about the scientific instrument makers' products, and in commercial instruments too short a range of usefulness in the instrument for practical men's experimental uses.

A search made recently for an ammeter and voltmeter which could be put in the hands of an intelligent plumber, workman, or student, to instruct him in the rudiments of electrical measurement, revealed the fact that nothing could be found suitable except very costly things.

Fig. 20.—Cheap Form of Daniell Cell

The instruments in the market are designed for placing on switchboards to indicate approximately the working pressure and the flowing current, and in many cases they are much more ornamental than useful. No one ever thinks of testing them. These remarks do not apply to the high-class products of our leading firms, in which the expert can see that the highest skill has been brought in to design and construct instruments of precision; but these refined apparatus are beyond the plumber's or student's means. What is required is a plain, fairly accurate, cheap instrument of a long range.

Whether this can be found or not is a question. Meanwhile, instruments devised by the author will be described, as an attempt to supply something to serve the purpose.

Current

If we send electric current round a wire ring, and place a compass needle in or near the centre, the axis of the ring being turned east and west, the needle will be deflected from its north and south position and turned more or less east and west, according to the strength of the current in the ring of copper wire.

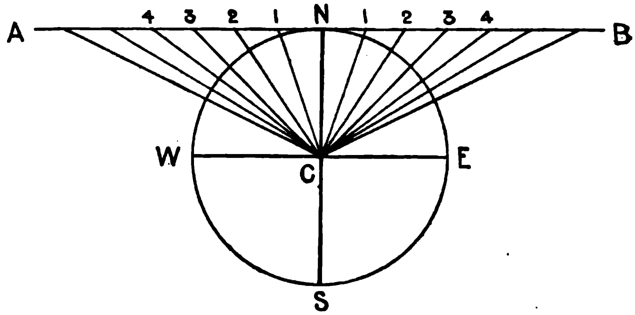


FIG. 21.—Tangent Scale

This simple device can be used to measure the current. The strength of the current is proportional to the tangent of the angle of deflection of the needle. A tangent scale for the dial of the needle could be made as follows :—

Take the dial, whether of metal or paper or glass; fix it on a sheet of paper on a drawing-board, as in Fig. 21; let the N S line be perpendicular, and from the point where this line cuts the circle described by the needle, draw a line at right angles thereto from A to B, and parallel with the line E W; divide this line in equal parts, beginning with zero at N, and numbering them 1, 2, 3, 4, right and left.

Join these points, 1, 2, 3, 4, to C, the centre of the dial, by lines, and mark the points of the circle where these lines cut it with corresponding numbers; these numbers then will be proportional to the angle tangent, and the strength of the current can be read directly on the dial.

Any one who makes this drawing of a scale will observe that the deflections, when they approach an angle of 90°, are far too close together for accurate reading; hence the scale is reliable only over a short range, say between 30° and 60° of deflection, 45° being the mean.

FIG. 22.—Tangent Galvanometer

Fig. 22 represents the ordinary instrument in its simplest form. Besides the limitation of the scale readings, it is limited in its range by the fact that if sensitive enough to read small currents at 25° or 30° deflection, it soon gets beyond 60°

or 70° deflection with stronger currents, and correct readings are difficult.

A modification of the instrument is shown in Fig. 23, wherein the wire ring is carried on a cross-shaped platform. The compass needle can be slid along the axial extension, so that it can be used for strong and weak currents; for strong currents it is used farther from the centre of the ring, and nearer for weak currents.

And further, instead of taking the tangent of the angle of deflection as indicating the strength of the current, we could make the copper ring of such a number of turns of wire as to produce a deflection of 45° with the smallest current we desire to measure, with the centre of the needle coincident with the centre of the ring; and a scale calibrated along the horizontal axial extension can be drawn and marked with the value of the currents at different points where the deflection is 45°.

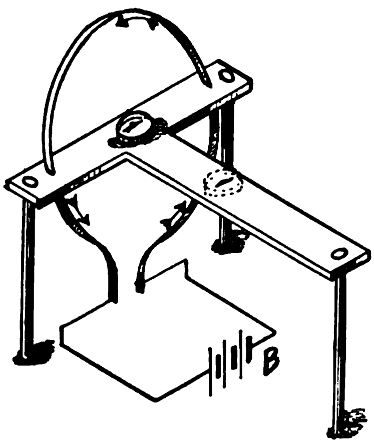


Fig. 23.—Simple Graded Ammeter

Whatever the strength of the current, the needle is shifted out or in until the deflection is 45°; its position on the scale shall then indicate the current in amperes. It is a constant deflection method of measuring.

For measuring currents the wire ring would be of thick wire to carry heavy currents.

For measuring pressure the wire ring would be of fine wire of high resistance.

Lord Kelvin's graded ampere and voltmeter are shown in the

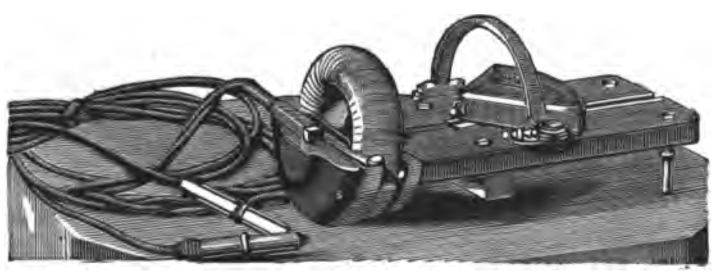


Fig. 24.—Lord Kelvin's Graded Voltmeter

accompanying Figs. 24 and 25. The coils of wire are shown fixed to the end of sliding table; the needles are carried in the sector-shaped boxes, and have a long light pointer swinging over a scale. The sliding table has a scale for multiplying the readings of the needles'

pointer. These instruments are of great value in a laboratory, due to their long range. A half-hoop magnet is shown over the needles. This produces a strong field controlling the needles, so that the instrument is nearly dead-beat. By removing the magnet in the voltmeter and placing the needles so that they are inside the coil, and the axis of the coil east and west, it can be used as a high-resistance galvanometer.

And similarly, the ammeter can be used as a low-resistance galvanometer for thermo-electric tests, and other experiments where large currents and low E.M.F. are used.

The instruments shown are expensive and finely got up for commercial purposes, but the design seems to lend itself to a cheap construction of instruments of a long range of usefulness for students; hence it has been chosen as a model for the rough experimental apparatus.

Ammeters are made with few turns of thick wire. The thick-

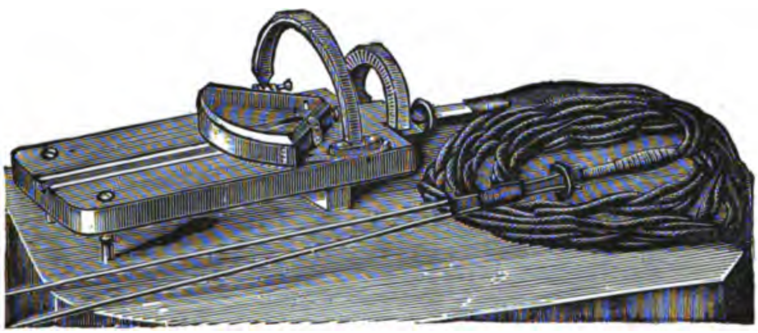


FIG. 25.—Lord Kelvin's Graded Ammeter

ness should be calculated to carry the maximum current without sensibly overheating.

This may be done from Table of Details of Conductors at end of the chapter. Say the ammeter is for five amperes maximum, a reference to the table shows No. 14 wire will carry 5.4 amperes at a loss of 2.5 volts per 100 yards.

The length of wire in the coil must not be long enough to reduce the volts more than a very small fraction. Hence, if the ammeter is to be used in a 100 or 200 volt circuit, a volt or 2 volts lost in it would be of no account; but if used on a 10 volt circuit, half a volt lost would be serious in an ammeter.

For instance, the experimental ammeter must be made for a 12 volt circuit; hence we must take about one-tenth of 100 yards of No. 14 wire to keep down the resistance of the ammeter to a value which would give a loss not exceeding 0.25 volts on full load.

In selecting an ammeter for any purpose, it is of great importance to know both the maximum current and the volts on the

circuit for which it is intended. If for a high-pressure circuit, the resistance of an ammeter is governed only by the limits to heating; but if for a low-pressure circuit, the permissible loss on the ammeter coils determines the size of the coil—the lower the pressure the larger the coil must be in thickness of wire and weight of wire, for we require the same number of turns in the coil whatever the gauge of the wire.

In a voltmeter the wire is chosen of a very small section and long length, so that the current passing into it is so small as to be negligible, when coupled right across the mains or terminals.

Its length and diameter must correspond to the maximum volts it is to measure.

5000 ohms in 100 volt circuit is common in coils of No. 40 and 42 gauge wire. For 10 or 12 volts 500 ohms of thicker wire is used.

The experimental instrument is shown in Figs. 26, 27, 28, and 29.

Fig. 26 is an end view, showing the wire coil C clamped in a brass or zinc plate with bent over clamps B B B, into which the coil fits; G is the compass needle case, which has guiding blades E, fitting into a groove in the stand shown at A in Figs. 27 and 28: these keep the compass case from turning round. The clamping-plate for the coil is screwed by brass screws to the end of a wood block $1\frac{1}{2}$ in. thick, $3\frac{3}{4}$ ins. broad, and 9 ins. long, a quarter-inch groove being run up the middle line. Alongside this groove the scale is sunk in flush, as shown at S S in Figs. 28 and 29. A pointer on the compass-box lies over the scale at P.

The compass may be bought for 1s. 6d. to 2s., with a needle about $1\frac{1}{8}$ to $1\frac{1}{4}$ in. long in a brass box with glass top; on the card should be drawn the 45° lines from N.E. to S.W., and from N.W. to S.E., through the centre in red ink.

The coil required for the pressure gauge consists of 5000 turns of No. 34 S.W.G. silk-covered wire, of total weight 14 ounces, on a wooden bobbin.

The scale is to be of stiff paper glued or gummed in. Two terminals, to which the ends of the wire coils are attached, T T, are shown into which the wires from the battery or other source of pressure is to be connected for measurement.

Two instruments are required, one with the fine wire coil for pressure, and one with thick wire for current; in other respects they are the same.

The pressure instrument should be made first, and graduated along the scale, by using the ten Daniell cells as standards of pressure. Proceed as follows:—

The instrument having been finished, and set with needle at

Students' Instruments

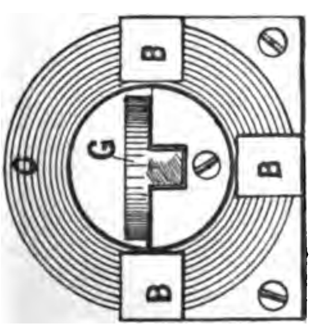


Fig. 26

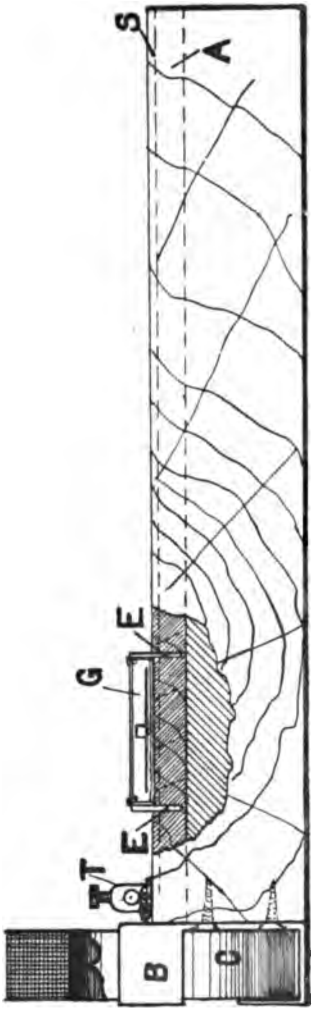


Fig. 27

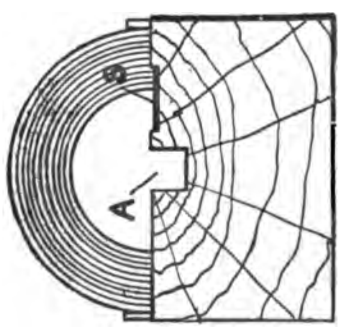


Fig. 28

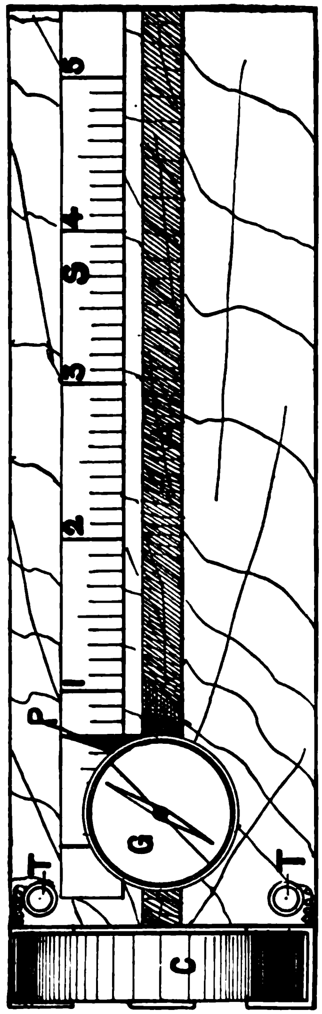


Fig. 29

Simple Ammeter or Voltmeter

right angles to the scale, a pair of wires are fixed into T T, insulated, and long enough to reach the battery of cells; first one cell is connected across, and the compass moved in and out until the needle is over the red line of 45° deflection; the point on the scale at the pointer P, Fig. 29, is then marked 1, as 1 volt pressure, then two cells are coupled on and the compass moved along until needle is over 45° line again; the pointer then stands at 2 volts, and must be marked 2, and so on with 3, 4, 5, 6, 7, 8, 9, 10 cells.

The scale can afterwards be subdivided, dividing the spaces between the marks into 10, so that $\frac{1}{10}$ths can be read.

To get the scale below 1 volt, say to half a volt, a resistance equal to that of the coil must be used in series with the one cell and coil; but a range between 1 and 10 volts may be sufficient for any one making the instrument himself.

The figures will not, of course, represent absolutely correct volts; but they will be for all practical purposes near enough the correct thing.

The cells should be in good order, the sulphate of copper solution in outer cells fully saturated, and the sulphate of zinc solution just about half saturated in the porous cell. The best way to ensure this is to make a saturated solution by adding sulphate of zinc to lukewarm water until it will dissolve no more, then let it cool, and pour off the clear solution, and add its own bulk of water; it is then fit for the cells.

After graduating this instrument, we have an electric pressure gauge. And with the help of this instrument we can now proceed to measure resistances, and make an instrument for the purpose.

The simplest instrument is called a metre bridge, from the fact that a wire one metre long is used in it, divided into millimetres along a scale. It might be a yard bridge by using a yard of wire divided into equal parts on a scale. But a long wire is better than a shorter one, so we may as well make it a metre bridge by using 40 inches of wire.

We will require a board 3 feet 6 inches long, about 5 or 6 inches broad, and $\frac{3}{4}$ or 1 inch thick, dry, smooth, and straight.

On the face of this board fix three strips of copper or brass, former preferred, $\frac{3}{4}$ broad by $\frac{1}{16}$ inch thick, or thereabouts, the long one 3 feet long, the short one 3 inches; total strip copper, 3 feet 6 inches.

Seven binding screws are required, two on each of the short strips and three on the long one, as shown in Fig. 28.

A high resistance polished wire, of No. 18 S.W.G. rheostene wire, is to be stretched between the short strips and secured thereto by soldering or screws.

A paper scale divided into 10, 100, and 1000ths from left to

right and from right to left is made, as shown in the figure. This is for the purpose of reading off what proportion the wire on the one side of contact bears to the wire on the other side.

Suppose we divide the wire into ten parts for the scale readings—

0	1	2	3	4	5	6	7	8	9	10
10	9	8	7	6	5	4	3	2	1	0

If we make contact in the middle, then, of course, it is as 5 is to 5, equal; but suppose we make contact at $\frac{7}{3}$, then the wire to the left is 7 as to 3 compared with the wire to the right of the contact. Again, we might make contact at $\frac{3}{7}$; here the ratio is reversed.

Referring to the drawings, Fig. 30 is a plan and elevation of

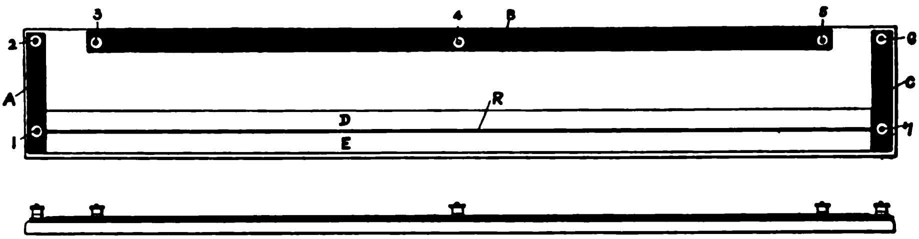


FIG. 30.—Simple Metre Bridge

the metre bridge. R is the resistance wire; D E the two scales; A C two copper strips, B long strip; a standard resistance is connected in between terminals 5 and 6, the resistance to be measured between 2 and 3, one end of battery to 4; galvanometer between 1 and 7, and the other end of the battery is used to make contact along wire R till a point is found where no current passes in the galvanometer. This is best observed by sliding the wire along until the needle is at zero, and then, by tapping the wires together, noting whether the needle moves to one side or other; if it moves to one side or other, tap it a little further along until a spot is touched where the needle does not move: the double scale can then be read at this spot. Fig. 31 is part of the scale shown full size.

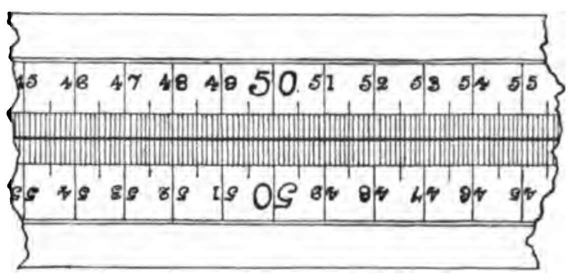


FIG. 31.—Section of Scale of Metre Bridge

When measuring low resistances under 10 ohms, three or four of the Daniell cells are used; for high resistances the whole ten are

required. The pressure gauge is used as a galvanometer when the needle is in or near centre of the coil, and is to be used with this bridge for measurements.

A standard 1 ohm resistance will be required. This can be bought for three or four shillings, or made by the student or workman if he can get some friendly electrician who has a resistance measurer to adjust it for him.

To make up a coil for a standard, take a little over half an ounce of No. 20 silk-covered German silver wire at 5s. per lb.; better get quarter of a lb., so that more coils can be made. Take the half-ounce piece (better be overweight); for while it is easily made shorter, it is not easily made longer. Cut it in two equal lengths, and put a little copper strip clamp over two ends, as shown in Fig. 32, so that when wound up the two wires will lie side by side; wind them on a wooden bobbin (an ordinary cotton bobbin will do), first passing the two free ends through holes in the bobbin to make connection to the terminals; wind it on and tie it down firmly; the two outside ends are now firmly bound together by the copper clamp, or by clean copper binding wires.

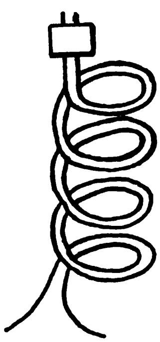


FIG. 32.—Resistance Coil

The coil is now to be tested and adjusted. For this purpose it must be put into a resistance measurer, commonly known as a Wheatstone Bridge, and there measured against a standard 1 ohm. If enough wire has been used its resistance will be more than 1 ohm. This can be reduced gradually by sliding the clamp along, thereby shortening the wires. This is done until the coil perfectly balances the standard on the bridge; the clamp is then securely soldered in the place so formed. The coil may have two small terminals fixed on it, and be fitted into a case.

Having either made or bought a standard coil of 1 ohm resistance, proceed now to make up a set of resistances for future use.

Take one pound of No. 16 manganin wire, cut it into five equal lengths (they will be about five yards each), wind them into spirals on a mandril or rod about 1 inch diameter, so that when taken from the rod the spirals will lie apart, and be about 1 foot long each.

Get ten terminals, fix them on edge of a frame of wood with the ends of the spirals securely fixed, one end to each screw.

These spirals will carry 10 amperes, and when doing so will have over 1 ohm resistance, and be nearly hot enough to boil water; but when cold they will be less than 1 ohm each, and by coupling them up in different ways we can get a great many different resist-

ances. If we put them all in series the total resistance will be about 5 ohms, and all in parallel 0.2 ohm, so that we have a resistance whose range is 25 to 1. Figs. 33 and 34 show this apparatus.

A second resistance frame can be made up with 1 ohm subdivided into $\frac{1}{10}$ths. Thus, take four ounces of the manganin No. 16

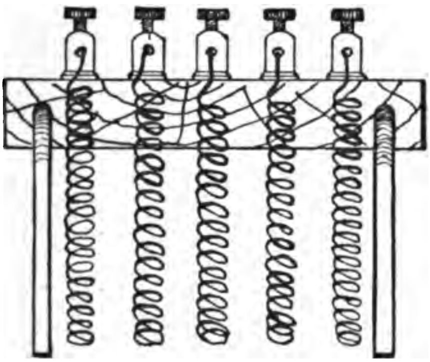


FIG. 33

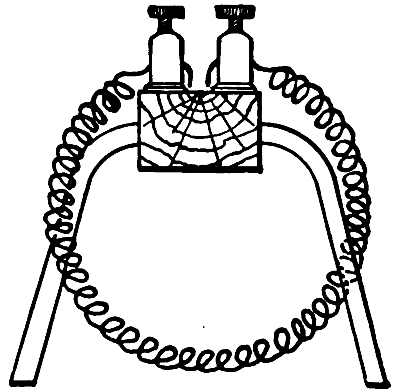


FIG. 34

Resistance Frames, with five Spiral Resistance Coils

bare wire about 6 yards long, fix on a board having eleven binding screws and ten brass hooks, as in Fig. 35; make it zigzag from one to the other, passing through the eyes of the binding screws and over the hooks tightly drawn in. A frame or board about 2 feet × 1 foot will be required; each screw then forms a terminal of resistances, increasing approximately by $\frac{1}{10}$ths. And if screws are used instead of hooks we could move step by step by $\frac{1}{20}$th of an ohm at a time. The screws cost about 1s. 6d. per dozen.

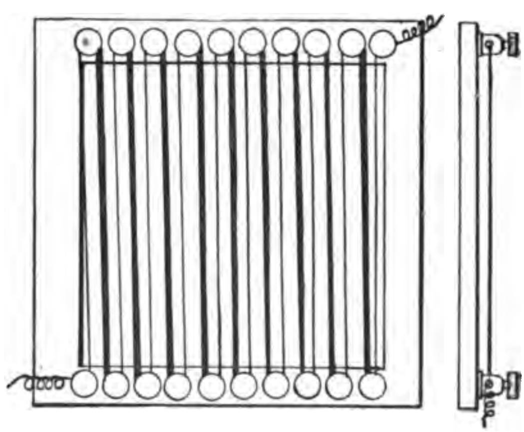


FIG. 35.—Resistance Frame

Reverting now to the metre bridge, we must learn how it works, what its principles are, and how to use it. Electricity under pressure flows from high to lower pressure, and we can control the current by altering the resistance, as it is always equal to $\frac{E}{R}$; hence, if we set up a circuit as in Fig. 36, where the current is divided between two paths, if the resistance of the paths are equal the current divides equally between them. And if we put a bridge wire across the two

exactly at their middle points, fine line shown, no current will flow from one to the other. And if we now put the bridge wire parallel, dotted line, with the first two, it will simply form a third path, and current in quantity equal to $\frac{E}{R}$ will also flow in it.

We will suppose the pressure equal to 1 volt between X and Y, the junctions of the wires, and the wires, say, 100 centimetres long, the pressure per centimetre would evidently be $\frac{1}{100} = 0.01$ volt per centimetre. This can be proved by putting a voltmeter connection from, say, X to O, the middle point of any of the wires, when half a volt would be shown.

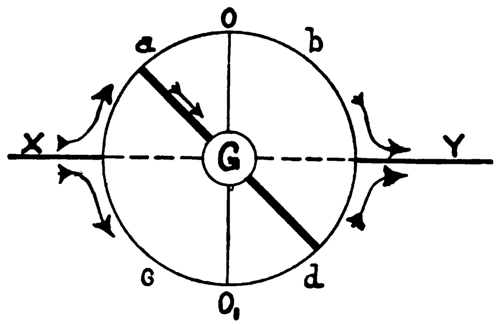


FIG. 36

The pressure between one point of the wire and any other point is proportional to the length of the wire between the selected points.

Now if we were to put the bridge wire across diagonally, as in the thick line on the figure, it would connect points of different pressures, and a current would flow proportional to the difference; so that if we rotated the contact bridge wire through a quarter of a revolution, we would put on from full pressure when making contact from X to Y, and no pressure when across from O to O_1.

Further, if we fixed the bridge wire across O to O_1, we could cause current to flow in it by altering the resistances in any of the wires *a*, *b*, *c*, *d*.

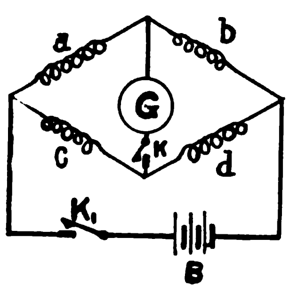


FIG. 37

Thus if we made *a* of thicker wire, the pressure would rise at O, and a current would flow indicated by galvanometer G. Only so long as the four paths *a*, *b*, *c*, *d* remain equal in resistance no current flows; but we can also balance the pressures at O O_1, so that no current flows, by altering two of the wires. It is not necessary all four sides should be alike.

In the bridge shown in the Fig. 37, *b* is a known resistance which can be adjusted and read; *a* is a resistance to be measured; *d* and *c* are known resistances, say, of 10 ohms, or one may be 10, the other 100. If they are equal, then, by adjusting *b* until no deflection is seen on G, then *a* is equal to *b*, which is known. If *c* was made ten times more than *d*, and *b* adjusted to a balance, *b* would be ten times *a*, so that it would be divided by ten to get value of *a*; and

if, on the contrary, we made *d* ten times more than *c*, we would multiply by ten to get resistance of *a*.

If, instead of this arrangement, we made *a* and *d* both vary, we could also make a balance (see Fig. 38). Let X form one side of a triangle, R another, and *a b* together form another, *a* and *b* being made variable by sliding the galvanometer wire along, the one becoming more as the other gets less, and *vice versâ: a b* is the metre wire. By sliding the galvanometer wire along we find a point at which no current flows. If R were equal to X, this point would be in the middle of the wire, where *a* would be equal to *b;* but if the point of balance were to the left, then X is to R as *a* is to *b;* hence, if on the metre scale the point was $\frac{25}{75}$, and R, the known resistance, 10 ohms, then

$$\frac{25 \times 10}{75} = 3.3 \text{ ohms, value of X.}$$

Again, it might be found to balance at $\frac{60}{40}$ on the other side. Hence

$$\frac{60 \times 10}{40} = 15 \text{ ohms would be value of X.}$$

In the metre bridge R should be somewhat of the order of X, that is to say, if X were known to be, say, less than 10 ohms, R should be anything between 1 and 10 ohms; and if X were known to be over 100 ohms, then R might be anything between 50 and 200 ohms, for small ratios are most easily balanced. The metre bridge set up for testing is shown at Fig. 39.

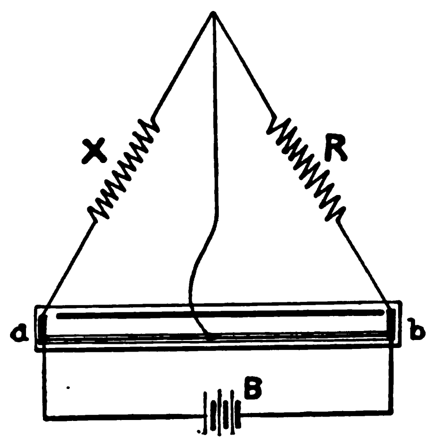


FIG. 38

B is the battery connected to the end strips; G is the galvanometer. In this instance the pressure gauge is used with the compass as near the centre of the coil as it can be got. R is the standard resistance connected at the gap *b*, and X is the resistance to be measured in gap *a*.

Having set up the bridge, the resistances made up should be carefully tested by placing them in gap *a* at X, and balancing against the standard 1 ohm coil. In the large resistance measure each coil separately and mark upon its resistance, and with the zigzag resistance measure each step and mark its value.

Having carefully measured the resistances and noted them, an ammeter can now be put in hand for measuring currents up to 5 or 6 amperes.

It is exactly the same as the voltmeter, only the coil is of thick

wire of few turns, and consists of forty turns of No. 15 cotton-covered copper wire on a wooden bobbin, shown half-size in the illustration.

To calibrate this ammeter we use the voltmeter and the resistances on the principles of Ohm's laws. If we know any two of the factors E, R, and C, we can find the third by calculation—

$$C = \frac{R}{E}.$$

So that we can make C any value we choose by adjusting E and R.

Thus if we take one of the large cells giving E = 2 volts, and make up a circuit consisting of the cell, the ammeter, and the resistances, we could make the total external resistance, including the ammeter and resistances, equal to 2 ohms. This we can do by coupling the resistances and ammeter into gap *a* on the metre bridge, all in

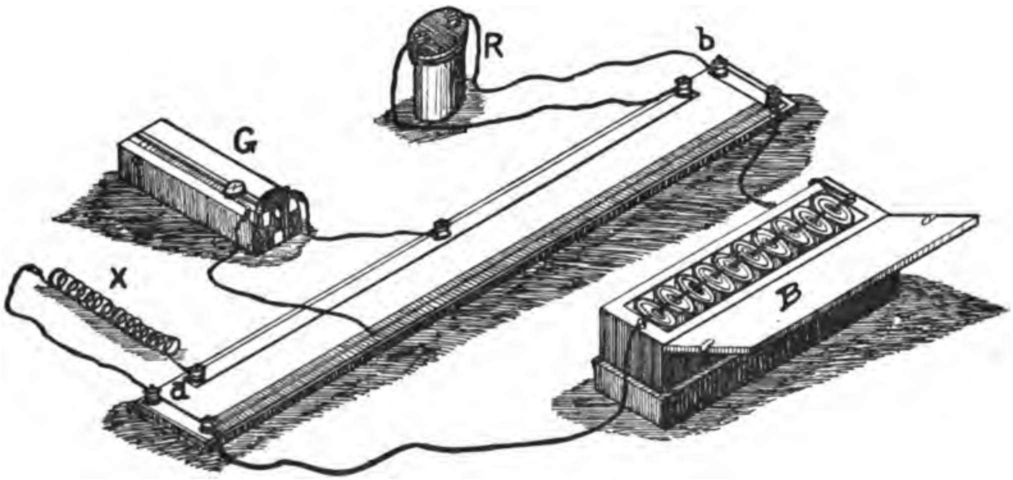


FIG. 39.—Testing with the Metre Bridge

series, and adjusting the resistance until we get it correct at 2 ohms.

As it is known the spirals are each about 1 ohm, we put two in the circuit, and finally adjust with the zigzag board $\frac{1}{10}$th at a time; the wire reading on the bridge would scale $\frac{73.5}{26.5}$ with the one standard coil. Fig. 40 illustrates this experiment where the spirals S are shown in series with the ammeter A and zigzag Z. If two spirals are more than 2 ohms, one must be used along with the zigzag, and if the ammeter coil is of higher resistance than 1 ohm, only the zigzag itself may be sufficient to make the circuit 2 ohms resistance. The work to be done in this experiment is to make the circuit 2 ohms resistance.

Having adjusted it to 2 ohms exactly, it is disconnected from the bridge and connected to one of the large cells without disarranging the series connections, merely taking the wires out of the

bridge and connecting them to the battery cell, as in Fig. 41. On no account must the ammeter or resistances be in any way moved or disturbed after adjustment to the 2 ohms resistance.

Immediately the battery is connected, as in Fig. 41, 1 ampere

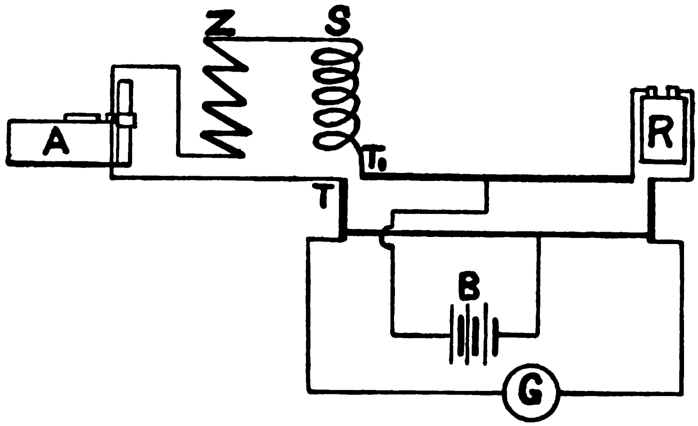


FIG. 40.—Adjusting Resistances

will flow in the circuit, as it is 2 ohms resistance with 2 volts pressure, $\frac{E}{R}=C$, $\frac{2}{2}=1$. And now move the compass in the ammeter until the needle is exactly over the 45° line, and then carefully mark the scale 1 ampere in that position.

And as a check, keep the voltmeter across the battery terminals, and note that it does read 2 volts at the moment the needle is adjusted on the ammeter. V is the voltmeter in the sketch.

Now put on two large cells, giving 4 volts with two in series, and therefore $\frac{4}{2}=2$ amperes; and with three cells in series $\frac{6}{2}=3$ amperes—and these points can be marked on the scale of the ammeter.

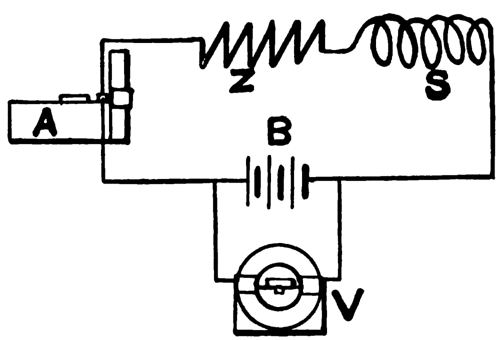


FIG. 41.—Calibrating Ammeters

For larger currents we must make a new circuit, and also for the smaller currents. Having got the 1, 2, 3 amperes points, we can now couple in the ammeter and resistances again into the metre bridge, and adjust a circuit of 4 ohms. For this purpose three spirals and the zigzag may be required in series, or perhaps two spirals and the zigzag. However, the student must work it out to 4 ohms exact.

Then repeat the test with the cells again; with one cell $\frac{2}{4}=0.5$

amperes will flow. This must be adjusted on the ammeter and the point marked.

Then put all the resistances in series with the ammeter, the five spirals and the whole zigzag, and measure on the bridge their total resistance; we will suppose it turns out to be 7.2 ohms.

Take off the bridge and put on the one cell again, and adjust the compass to 45° again, and mark the point $\frac{2}{7.5} = 0.28$ amperes; this will be the smallest current we can get with that arrangement and resistances.

Then, again, to get larger readings, couple up the battery in series parallel, take four cells and join them up two and two in parallel, as in Fig. 42. The two + poles of cells *a* and *b* are joined together by the copper leading wires. The negatives of *a* and *b* are then joined by good conductors to the positives of *c* and *d*, and the negatives of *c* and *d* are joined together by the negative lead.

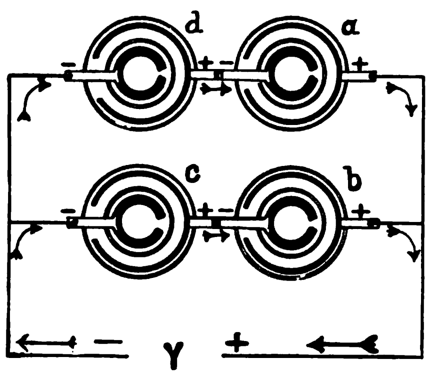


Fig. 42

a and *b* are in parallel, and *c* and *d* are also in parallel connection; *a c* are in series, also *d b*.

By placing the pairs in parallel we virtually make the two cells into one; so that if we took, say, 10 amperes from the leads at Y, each cell would only require to give 5 amperes, the amount it was designed for. Then we put them in two series by joining the two pairs + to —, adding their pressures to get 4 volts. It is plain that by this coupling up of the cells 4 volts and 10 amperes can be obtained.

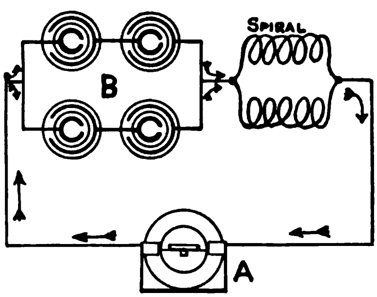


Fig. 43

The ammeter circuit can be now made up for a large current, first by connecting two spirals of the large resistance in parallel and in series with the ammeter and battery, as in Fig. 43.

Each spiral may be 1 ohm; but to make sure of the value of the resistance of the circuit, couple it into the bridge before coupling on to the battery, and measure it and adjust its resistance to 0.5 by putting in more or less of the spiral resistances.

Two spirals joined in parallel, as shown, have together only half resistance of one, for the current divides between them. If each is 1 ohm, the two in parallel will be 0.5.

Having adjusted to 0.5 the whole circuit's resistance, spirals, ammeter, and connections, then connect on to the battery, as in Fig. 43. Adjust the compass again on the slide till needle is at 45°, and mark the position carefully.

As we have 4 volts and 0.5 resistance, the current will be $\frac{4}{0.5} = 8$ amperes, the figure to be marked on the scale at this point.

Then alter the resistance of the circuit to 0.8 ohms, and take another reading of the ammeter and mark the scale $\frac{4}{0.8} = 5$ amperes. And so for finding the spot corresponding to 6 amperes alter the resistance to 0.66 ohms and take a reading, and for 7 amperes the resistance will require to be 0.572.

The workman or student who goes through with this course of practical work may not produce very accurate instruments, nor may his results be all correct; that, however, is of no account. But he will have what is of extreme value to the beginner—a practical knowledge of the quantities meant by volts, amperes, ohms, resistance, watts, and of the various circuits in use.

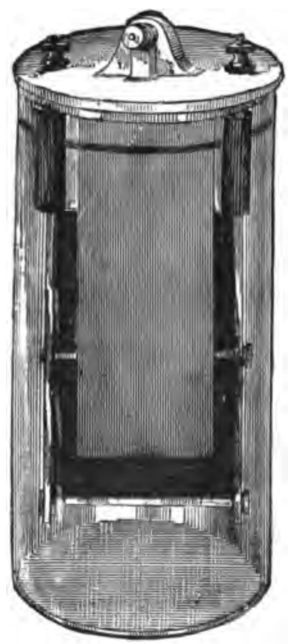


Fig. 44.—Edison-Lalande Type Cell.

At less expense and labour better apparatus could possibly be purchased, but the experience cannot be bought at any price.

The student or workman should also carefully go through an elementary book on magnetism and electricity, such as A. Jamieson's "Manual of Electricity and Magnetism," or Prof. S. P. Thomson's "Elements."

An alternative set of apparatus may be used in which the battery is of the Edison-Lalande type (Fig. 44), giving 0.75 volts, and with an internal resistance of 0.03 ohms. A 4 ampere current would drop the volts to $0.75 - (4 \times 0.03) = 0.63$ volts per cell; ten cells would give 6.3 volts and 4 amperes = 25.2 watts.

And the instruments might be the General Electric Company's battery gauges shown in Fig. 45.

The gauges are made for pressure and current; the current gauge reads to 4 amperes, the pressure gauge to 6 volts. It is shown in figure below.

With these cells and instruments the experiments can be made on a smaller scale; they are very useful and handy. The battery

is less messy than the high-pressure two-fluid cell battery, the liquid being potash solution.

If these are used the experiments described must be modified to suit the lower pressure; thus, in the series system investigation the lamp must be a 2 volt lamp, and the whole resistance of the circuit about 8 ohms (cold).

If these apparatus are chosen for the battery and instruments, only that one battery will be required, as it can be used for the bridge and all other tests. The student will then only have to construct the metre bridge, resistances, and circuits.

The making of the apparatus and adjusting it all is a necessary training before attempting the use of it. Any one who has carried out the work can be quite safely trusted to use more accurate and expensive instruments and apparatus afterwards.

FIG. 45.—G.E.C. Battery Voltmeter

Experiments with the apparatus can now be pursued to get a further insight into electrical circuits. Beginning with a series circuit, take the large cells, six of them giving 12 volts, and prepare to make tests with the voltmeter, investigating the practical conditions of a series circuit.

Let a number of different electrical energy consuming devices be put in circuit with the battery of 12 volts (Fig. 46): first the ammeter; next the resistances; next a small 4 volt lamp; next a small electro-magnet, a short piece of iron with a layer or two of No. 16 copper wire, cotton covered; and next a cell for electro-chemical work—this may be a jam-pot with a solution of sulphate of copper in a 1 to 10 solution of acid sulphuric and water, into which two plates of copper are immersed and connected in the circuit. The wire from this cell completes the circuit by going to the other pole of the battery.

The 4 volt lamp should be of low resistance, not more than 4 ohms (hot), that will be about 8 ohms (cold).

Now before coupling on the battery make a resistance test of the whole circuit, and by means of the resistances in the circuit

reduce it to a total of about 15 or 16 ohms, using the ten Daniell cells for the test, and if possible 10 ohms for the standard resistance.

Now couple on the battery after having carefully noted the resistance of all the lot and made it as directed. Adjust the ammeter, and read the current off; it will be found about 1 ampere, not

$$\frac{12}{16} = 0.75,$$

as we might calculate from the resistance.

This is not due to any error in calculations, but to the fact that the resistance has dropped. The lamp has only half the resistance when hot that it has when cold, a fact well known.

In fact, heat increases the resistance of metals and decreases the resistance of the carbon, of which the filament of the lamp is made.

If the current in the circuit is not 1 ampere, make it so by adjusting the resistances in the circuit until it is 1 ampere.

Now consider this circuit. First we have the source of electrical energy keeping up 12 volts pressure, as is shown by connecting the

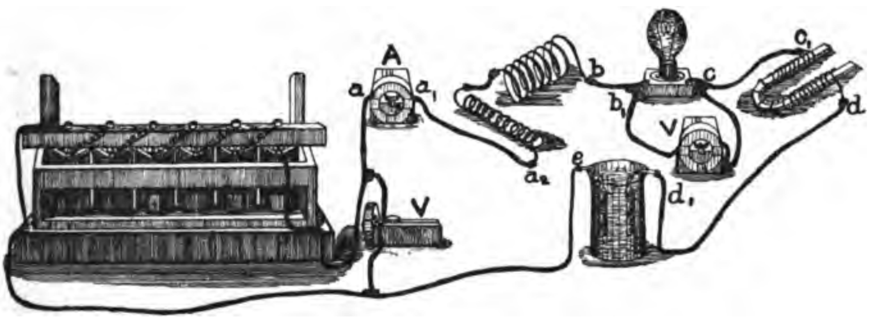


FIG. 46.—Experimental Series Circuit

voltmeter V across the battery terminals; next the ammeter showing the current flowing; next the resistances, regulating the current by adjusting the resistance of the whole circuit; next the lamp, where electrical energy is being converted into light and heat; next the magnet, which acts as a resistance and gives a magnetic field; next the cell of copper solution, with copper plates, in which copper will be carried from one plate to the other by the current, so that if the plates are weighed before starting the experiment, and weighed again at the close, one will be heavier and the other lighter.

The strength of the current in amperes must be the same all round the circle, for the current cannot be greater in one part of a circuit than in another.

Let the current flow, and watch the ammeter carefully, continually adjusting it till it remains steady at 1 ampere.

It will not be steady just at first, for the various parts of the

circuit will vary in resistance until they all attain a constant temperature. All resistances get heated by current.

Now investigate the circuit with the voltmeter and find out how the pressure of 12 volts is used up in the circuit. First join the voltmeter across the terminals of the ampere meter from $a\ a_1$, without disturbing the circuit or the current; it indicates, say, 0.5 volts, showing that half a volt is lost in pushing the 1 ampere through this instrument. Now put it across the resistances, that is, from a_2 to b in figure; it may indicate 5 volts, showing we are using up 5 volts in the resistances, simply heating them. Now put the voltmeter across the lamp from b_1 to c; it indicates 4 volts lost in the lamp, giving light in return.

Now measure across the magnet c_1 to d. It may show 0.75 volts used up in its coils, and finally the cell; 1.75 volts is indicated from d_1 to e. If we table the results we shall see how the pressure is used in this circuit:—

	Volts.		Amp.		Ohms.
Ammeter	0.5	÷	1	=	0.5
Resistances	5.0	÷	1	=	5.0
Lamp	4.0	÷	1	=	4.0
Cell	1.75	÷	1	=	1.75
Magnet	0.75	÷	1	=	0.75
	12.00	÷	1	=	12 00

The whole 12 volts are used up by the circuit carrying 1 ampere, and thus by Ohm's law—

$$R = \frac{E}{C}.$$

In above table E is found for each piece in the circuit by the voltmeter, and the current is indicated by the ammeter, so that we can tell their resistances at once by dividing by the current.

Having measured everything, the experiment may stop, the plates in the cell removed and weighed; and if the time during which the current flowed through has been carefully noted in seconds or minutes, it will be found that copper at a certain rate has been carried across for every second current has been on. If the current has been flowing for an hour and the ammeter correctly indicates 1 ampere, then there should be 0.00295 pounds of copper dissolved from one plate and deposited on the other.

The plates should be about 3 inches by 2 inches, immersed, and if set up as directed for a copper voltmeter it will be an interesting result to weigh the plates to check the ammeter's correctness.

In this experiment the distribution of the electric pressure is the point to observe. It is portioned out simply in accordance to the resistance of each piece, and the current depends on the total resist-

ance of all the lot. If the resistance of any part changes then the current drops, and the pressure on all the pieces also drops. To impress this on the mind, let the lamp be replaced by a piece of short copper wire and the current put on again, and a table of the pressures across the parts or pieces in the circuit be again taken and the current read.

It will be found the current has increased in proportion to the decreased resistance of the whole circuit, and the pressure on the remaining pieces has been increased also.

In the second experiment (Fig. 47) to be made the tests must be made on a parallel system. Take two cells of the battery in series, and from the wires *a b* connect the resistances and the lamp in parallel, and the voltmeter in parallel, the ammeter in series. It will be noticed that wherever the voltmeter may be coupled across between the mains the pressure is the same. Disconnect the resistances, the pressure is still the same; take off the lamp, pressure is still the same. But look at the ammeter; every change made tells there now. When both resistance and lamp is on the current may

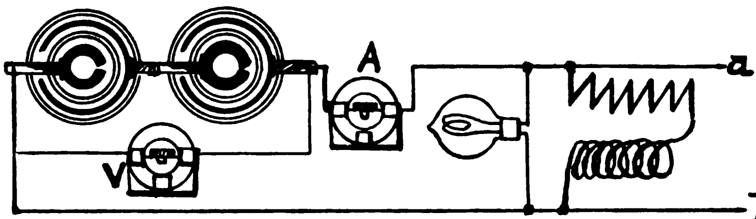


FIG. 47.—Experimental Parallel Circuit

be 2 amperes, with one of them on 1 ampere, and by varying the resistances any current between 1 and 2 amperes obtained; yet the voltmeter remains steady at 4 volts.

In the series system, if the pressure is constant at the ends of the circuit, the current varies with any change in R throughout the whole circuit.

And as in practical series systems every piece in the circuit is designed to take the same constant current, it is necessary, if we reduce the number of pieces, to also reduce the pressure, so that the current may be constant.

In the parallel system the pressure remains constant whatever changes we make on the pieces, and each piece is totally independent of the others. All the pieces, lamps, or motors are made to work with the same pressure, but may be made for any current, lamps taking 20 amperes working peacefully alongside of one taking half an ampere.

The third experiment is made to demonstrate the fall in pressure in wires and the benefits of high pressure.

Ohm's Laws

We have seen that the pressure is lost as the current passes through anything in proportion to its resistance, strikingly shown in the tests on the series system. For instance, we saw that the resistance of the spiral and zigzag caused a fall of 5 volts, that being the pressure measured between their two ends, with 1 ampere flowing; if we raised the current to 2 amperes we would find 10 volts of difference, R being 5 ohms and C 2 amperes.

But let us consider the matter from a power or energy point of view. In the first case, 5 volts × 1 ampere gives 5 watts lost in that resistance.

In the second case, 10 volts × 2 amperes gives 20 watts, so that, while we have doubled the current flowing, we have four times the loss of energy in the resistance.

Hence we say that the loss in a wire or resistance is as the square of the current, which is quite true, but somewhat misleading. In fact, as we have just seen, the loss is directly proportional to C × E or the watts.

We doubled the current by doubling the pressure; hence the loss is as the square of the current.

But we could double the current without doubling the pressure, that is, by halving the resistance—

$$\frac{5\text{ volts}}{2.5\text{ ohms}} = 2\text{ amperes.}$$

Here the loss is $5 \times 2 = 10$ watts.

The question is this: we have to deliver so many watts of electrical energy through a wire to a distant point, *not current nor pressure alone*—we want something with horse-power in it. The wire has resistance which absorbs power; the smaller the current the less the loss, as it is equal to $C^2 \times R$.

Hence, we get the same power delivered with less loss if we use a smaller current and a larger pressure.

Watts = 746 may be sent along under 746 volts pressure, in which case 1 ampere would be required.

And as the 746 volts and 1 ampere are wanted all at the far end, there must be at the near end as much more pressure as will overcome the wire's resistance. We will suppose the wire to have 50 ohms resistance, there and back; it will then take 50 × 1, or 50 volts, for the wires, so that the dynamo would require to have 796 volts pressure to supply this current at the far end.

If we required 2 amperes delivered by the same wire, the 50 ohms of wire would require 100 volts of pressure, 746 + 100 = 846 volts, to squeeze the 2 amperes through, and the loss would be 100 volts with 2 amperes, or 200 watts, while with 1 ampere the loss is 50 watts. The loss is as the square of the current *in the same wire.*

But suppose we increase the pressure instead of increasing the

current. We increased the current from 1 to 2 amperes, doubling the power delivered with four times the loss. Now let us again consider the current at 1 ampere, and double the pressure to 1492 volts at far end, the loss on the wire will be the same as at first, 50 volts, which added to $1492 + 50 = 1542$ volts at dynamo end.

The loss in the first case is 50 on 746, in the second case 50 on 1492; by doubling the pressure we deliver twice the power with the same loss in pressure.

Suppose we double the pressure and half the current, that is, deliver the same power by same wire as in first case, then 0.5 amperes × 50 ohms = 25 volts required for the wires alone.

The loss in watts in first case—

$$50 \times 1 = 50 \text{ watts} = \text{power delivered watts} = 746$$

The loss in watts in second case—

$$100 \times 2 = 200 \text{ watts} = \quad " \quad " \quad = 1492$$

Third case—

$$50 \times 1 = 50 \text{ watts} = \quad " \quad " \quad = 1492$$

Fourth case—

$$0.5 \text{ amperes} \times 25 \text{ volts} = 12.5 \text{ watts} = \quad " \quad " \quad = 746$$

These results we get by using volts and amperes and ohms; but we could arrive at same results on the C^2R theory:—

First case, . .	$1^2 \times 50 = 50$	watts	lost.
Second case, .	$2^2 \times 50 = 200$	"	"
Third case, . .	$1^2 \times 50 = 50$	"	"
Fourth case, .	$0.5^2 \times 50 = 12.5$	"	"

It seems immaterial what formulæ is used, but there is a difference in methods although not in results.

In the second case, although we have squared the loss in the wire, we have twice the power delivered, so that the loss per horse-power delivered is only doubled. In the third case we have doubled the power delivered without increasing the loss any at all.

In the fourth we get the same power as in first case at half the loss.

Any wire should be worked at a certain density of current, 1000 amperes per square inch for short lengths and less for longer ones.

So that if we have a wire capable of carrying 10 amperes, it should be worked as near that current density as possible, and to get most power out of it the pressure should be as high as possible. At 746 volts it would carry 10 horse-power, at 1492 volts 20 horse-power, and so on; to these pressures always adding that required by the wire itself.

Take two wires of 1 ohm resistance, capable of carrying 2 amperes, attach them to three of the Silvertown cells or ten Edison-Lalande, and to their other ends attach the variable resistance spirals. And take the volt and ampere readings with various cur-

rents at various points in the circuit; make the resistances so that 2 amperes pass through the circuit; measure the volts across the terminals of the battery, then across the terminals of the resistance in circuit; their difference will give the loss in the wires at that current. The reading at the battery end is the full pressure of the battery externally; the reading at the resistance is the available pressure for work at that end.

The circuit consists of two wires of 1 ohm each, and the resistance might be 1 ohm also; total, 3 ohms (external resistance). And the battery may give, say, 6 volts, so that total current $\frac{6}{3} = 2$. These figures are all to be found by measurement; those quoted are only instances of what might be. The student should measure and find how much pressure is lost in each part of the circuit, the leads, and the resistance; and taking the full pressure at the battery when current is flowing, should calculate how much is lost in the leading wires, and how much is left for work on the resistance at far end.

A model three-wire system is also instructive. With the low-pressure battery 6 volt lamps may be used of one candle-power each, the battery divided into two series of five each. Couple the ammeter into the third wire between the first lamp and the junction of the two halves of the cells, and note the readings when lamps are turned off one by one on either side. Eight or ten lamps will be required.

Other experiments will suggest themselves, but in all experiments carefully calculate what currents and pressure you purpose using, and keep them within the capacity of apparatus.

In using an ammeter it must always be connected in series with the circuit; an examination of the various diagrams shows this invariably. Ammeters have been accidentally connected in parallel with other apparatus in a circuit with disastrous results, as they are of low resistance and take an immense current if subjected to the full pressure. When connected in series they are subjected to a pressure only proportional to their resistance and the current passing.

Thus an ammeter for 50 amperes may have a resistance of 0.05 ohm, and as

$$C \times R = E, \quad 50 \times .05 = 2.50,$$

2.5 volts would be the highest pressure between its terminals when in series with 50 amperes flowing.

The terminal pressure of the circuit might be 100 volts, so that if the ammeter were accidentally, or otherwise, connected across in parallel, it would get current, according to Ohm's law, equal to

$$\frac{100}{0.05} = 2000 \text{ amperes.}$$

It would practically never get such an immense current, for several

other things would happen: first, the meter would be burnt up, its coils in all probability melted, or the safety fuses or cut-outs would be blown out.

There is a class of ammeters working on the principle of Ohm's law which may here be described so far as that law applies to them.

We have seen by our experiments that the voltage or pressure at the ends of a resistance is strictly proportional to the resistance (see Tables of Tests) and current flowing.

Hence, if we connect a voltmeter with its wires attached one to each end of a resistance, the readings of the voltmeter will be strictly proportional to the current, and the voltmeter may be graduated and marked to read amperes.

This is a very convenient construction for large currents, for it is extremely difficult to put in wires heavy enough to carry hundreds of amperes in a meter.

The resistance R is in series with the current in Fig. 48; G is the generator, and V the voltmeter, with its two wires attached to the ends of the resistances.

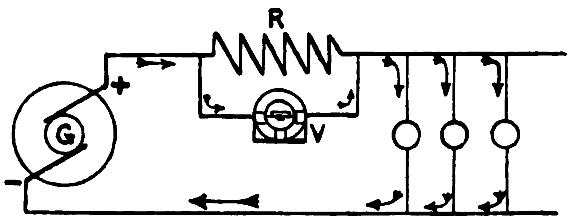


FIG. 48.—Shunt Ammeter

The calculation of the resistance is easy. It must not cause a serious drop in pressure at full load, and yet it must have enough resistance to show an appreciable difference of pressure at $\frac{1}{10}$th or $\frac{1}{20}$th of full current.

Assume the permissible drop in pressure in the resistance at full load to be fixed at 2 volts for a current of 200 amperes, what should R be?

$$R = \frac{E}{C}.$$

E is 2 volts, C = 200 amperes;

$\frac{2}{200} = 0.01$ ohm would be the resistance required.

What would then be the pressure at the ends of this resistance when 20 amperes flow through it?

$$E = C \times R = 20 \times .01 = 0.2 \text{ volt.}$$

This clearly proves that the voltmeter would require to work with a range between 0.2 volt to 2 volts; and it would read correct amperes if we multiplied the scale readings by 100. This method of measuring current is called a shunt, as the current is in part shunted past the meter.

Voltmeters are always connected with one wire to one point, and another wire to another point, between which pressure is to be

measured. If we wish to measure the pressure of a dynamo, we put the wires one in each terminal; but we must be careful to select a voltmeter which we know will read up to the expected voltage or pressure. We must not put an instrument designed to read up to 10 volts only, upon a 100 volt circuit; it would be burnt up.

Enough has been shown to prove the value of Ohm's laws, and the student should spare no time and trouble to understand these examples, so that, when given any two of the factors E, C, R, he can always calculate the third.

With an ammeter and voltmeter he can get to know what E and C are in any circuit.

Suppose in an electrical circuit running all day there is a motor with a faulty resistance in series, and it is desired to replace the resistance, and it is required for that purpose to be known what its resistance is, without stopping the motor or taking out the resistance, all that is required is to take the value of the current flowing in the motor by an ammeter, easily put in without stopping the motor, and then by a low-reading voltmeter connected to the two ends of the resistance find the pressure E. Thus we have found the E on and the C in the resistance to be calculated out,

$$\text{and} \quad R = \frac{E}{C} = \frac{5}{10} = 0.5\,;$$

if E were 5 volts and C 10 amperes, the resistance must be $\frac{5}{10} = 0.5$, or $\frac{1}{2}$ an ohm.

Without Ohm's laws the electrical engineer would be helplessly lost to find out anything about his circuits.

In practice it is E and C that are usually measured, and R calculated.

Note also that when resistances are in series, their pressures are added to find the total pressure required to send current through. But if we put resistances, motors, or lamps in parallel on a circuit, the total resistance is reduced by each parallel.

Thus when a circuit divides into a number of parallel branches, the joint resistance of the lot is obtained by two methods. If there are two parallel branches, A and B, then their joint resistance is equal to

$$\frac{A \times B}{A + B} = R\,;$$

thus A may be 5 ohms and B 10 ohms; then,

$$\frac{5 \times 10}{5 + 10} = \frac{50}{15} = 3.\dot{3} \text{ ohms, total combined R,}$$

their joint resistance.

Another method is to measure each branch separately, and add the reciprocals of the numbers so obtained, the sum being the reciprocal of the number giving their joint resistances. Take three circuits in parallel with 2, 5, 10 ohms resistance.

Resistances in Parallel

The reciprocal of a number is 1 divided by that number:—

No.		Reciprocal.
$\frac{1}{2}$	=	0.5
$\frac{1}{5}$	=	0.2
$\frac{1}{10}$	=	0.1
Joint reciprocal		0.8

The number corresponding to the joint reciprocal is $\frac{1}{0.8} = 1.25$ ohms total resistance, and so for any number of parallels.

If we had all the parallel connections equal in resistance, as we have in a group of incandescent lamps of equal power, then we simply divide the resistance of one lamp by the number of lamps.

Thus if we had fifty lamps in parallel, each of 150 ohms, their total resistance would be $\frac{150}{50} = 3$ ohms.

Adding lamps or motors in series multiplies the resistance in a current.

Adding lamps or motors in parallel divides the resistance by the number added.

For mixed circuits, tables of reciprocals of numbers can be used in calculating the total resistances very conveniently. These tables are so common that we do not here include them. Pocket-books for electrical engineers, such as Prof. Jamieson's and Geipel and Kilgour's, are full of these tables for all purposes.

To recapitulate, the current is the quantity of electricity flowing in any circuit; it is measured in amperes by ampere meters, which indicate the quantity flowing; it is represented symbolically by C.

Pressure or voltage, or electro-motive force, is represented by E in formulæ; is measured in volts by voltmeters. When we examine an electric circuit in which current is flowing by means of a voltmeter, we find the pressure is distributed over the circuit in proportion to the resistances of the various parts. Thus, if we apply the voltmeter wires to two sides of a lamp, one to the positive terminal and one to the negative terminal, a difference of pressure is shown. It may be an arc lamp taking, say, 50 volts between the terminals, and it may have a current of 10 amperes flowing, in which case its resistance will be $\frac{E}{C} = 5$ ohms. The circuit, however, may have at its terminals 65 volts, so that a resistance to absorb 15 volts pressure must be put in series with the lamp; to absorb 15 volts at 10 amperes, we require $\frac{15}{10} = 1.5$ ohms in this resistance.

These pressures have been called "potential differences," that is to say, the "potential difference" between the main wires is 65

volts, between the ends of the resistance 15 volts, between the arc lamp terminals 50 volts. Hence some writers use P.D. as a contraction for Potential Differences at any points in a circuit.

Reverting to the tests on the series circuit, the P.D. between the lamp terminals would be 4 volts, the P.D. between the ends of the resistances 5 volts, P.D. between the plates in the cell 1.75 volts, and the P.D. between the terminals of the battery 12 volts.

Now there is no difference in the meaning of the words P.D., or Pressure, or Voltage, between two points in a circuit. There is a difference, however, between the meaning of these terms and Electro-Motive Force, shortly written E.M.F., and P.D.

E.M.F. is the total pressure in the whole circuit.

The cells, for instance, have 2.08 pressure or P.D. between the terminals when no current is flowing. The E.M.F. is equal to the P.D. or pressure when no current flows; but immediately we allow current to pass the P.D. at the terminals falls, because although the E.M.F. is still 2.08, some of it is employed inside the cell to drive the current through the cell itself, lowering the terminal P.D.

Hence it is necessary to distinguish between P.D. or pressure and E.M.F., for while P.D. may be varied at pleasure, the E.M.F. which causes the pressure may be, and generally is, constant.

In dynamos the same thing occurs. A dynamo of ordinary shunt or separately excited type has a constant E.M.F. if the speed is constant and the field-magnet constant; but the P.D. at its terminals falls as current is put on, due to the E.M.F. being used up in the inside of the machine.

It is the same in hydraulics. Water may have a height which produces 100 lbs. pressure per square inch on the end of a closed long vertical pipe; but if the water is allowed to flow, the pressure will no longer be proportional to the height, but will be less. The height which causes the pressure is hydraulic motive-force; the pressure, the P.D.

The E.M.F. of a battery or dynamo, or other so-called electric generator, is given at the terminals only when little or no current flows; and the P.D. varies as the current.

It may be said that many dynamos can be seen at work with a constant P.D. at the terminals whatever the current taken; in fact, some dynamos increase in P.D. the more current taken from them.

These apparent contradictions are only proofs of the theory, for in constant P.D. generators some device is employed whereby the E.M.F. increases as the current increases, and hence the P.D. is kept constant by this extra E.M.F.; and in cases where the P.D. actually rises with increase of current, the E.M.F. is increased in a greater amount than necessary to overcome the internal resistance.

Resistances are not always the same in kind. The ordinary resistance of metals and other conductors is called "ohmic" resistance, to distinguish it from other resistances.

Ohmic resistances convert the electrical energy into heat. An ohmic resistance reduces the current by wasting the pressure inside itself, and being heated thereby much in the same way as a mechanical brake acts. A brake applied to a wheel driven by power wastes the power and becomes heated; the amount of heat being the measure of the power wasted.

In an electric resistance the heat generated is equal to the watts passing through it—$C \times E$, E being the P.D. at its ends and C the amperes. In other words, the heat is proportional to the C^2R rule if we take current and resistance only into account.

On this principle of heat conversion in a conductor many of the electrical engineers' appliances work. Arc lamps, incandescent lamps, electric welding, and other apparatus operate simply by converting electrical energy into heat. Ammeters and voltmeters are made working on the principle of heating conductors by electricity.

Electricity all too readily runs down to heat and is so lost, for no known process can reverse the action, that is, convert electricity back from heat with any economy.

Electrical energy may be expended in heating; in electromagnetic motors giving motion to machinery; in lamps giving light; in chemical action in cells giving metals and chemical compounds. But however expended, the amount can be measured in watts by finding the current and P.D. acting from terminal to terminal; these multiplied together give the power in watts. One watt is equal to 44.25 foot-lbs. per minute.

The mechanical horse-power is equal to 33,000 foot-lbs. per minute, or 550 foot-lbs. per second, the watt being equal to 0.7375 foot-lbs. per second.

It is with these figures always easy to calculate the work done in any circuit or any part of a circuit, simply by measuring E and C. And $E \times C \times 44.25$ will give us the foot-lb. per minute, from which it is easy to find the mechanical work done in horse-power—

$$\frac{33{,}000}{44.25} = 746 \text{ watts.}$$

Mechanical horse-power = 33,000 foot-lbs.
Electrical horse-power = 746 watts.
746 watts being also = 33,000 foot-lbs.

A few tables of resistance metals and useful data regarding circuits of wires are here inserted by kind permission of Messrs. W. T. Glover & Co.

The data and numbers are exceedingly useful in selecting wires to make up any given resistances. Manganin and rheostene are

Useful Tables

Messrs. Glover & Co.'s special resistance metals. Also for copper coils for voltmeters, ammeters, motors, and dynamos.

Table I.—*Resistance Metals*

Size. Birmingham. W.G.	Diameter. Inch.	Diameter. M/M.	Yards per lb., bare.	Iron. Ohms per lb., bare.
14	.083	2.1082	16	.457018788
15	.072	1.8290	21	.80637168
16	.065	1.6510	26	1.21504620
17	.058	1.4732	33	1.91661780
18	.049	1.2446	46	3.7623852
19	.042	1.0668	62	6.9703056
20	.035	.8890	90	14.4550544
21	.032	.8130	108	20.6845644
22	.028	.7110	140	35.2883328
23	.025	.6350	176	55.5252168
24	.022	.5590	228	92.588244
25	.020	.5080	275	135.558312
26	.018	.4570	340	206.612868
27	.016	.4064	430	330.953412
28	.014	.3556	562	554.592464
29	.013	.3302	612	759.40944
30	.012	.3048	765	1045.97832
31	.0115	.2920	833	1247.355
32	.0110	.2793	910	1490.081856
33	.0100	.2540	1101	2003.33004
34	.0095	.2412	1220	2678.473296
35	.0087	.2209	1455	3808.06272
36	.0079	.2006	1764	5601.093
37	.0073	.1854	2066	8134.59264
38	.0068	.1727	2381	10202.076
39	.0063	.1600	2774	13849.02084
40	.0058	.1473	3273	19277.796
41	.0050	.1269	4405	34904.952
42	.0040	.1016	6880	85166.96
43	.0030	.0760	12256	281417.916

Table II.—*Manganin Wire.*

Current giving 212° Fah. (100° C.) rise in temperature above the surrounding air. These figures are correct only for wires stretched in a horizontal position and freely exposed to the air; when placed vertically or when coiled an allowance should be made.

S. W. G.	No. 8	9	10	11	12	13	14
Amperes	60	50	40	35	30	25	20

S. W. G.	No. 15	16	17	18	19	20	21
Amperes	15	12	10	9	8	6	5

Useful Tables

Table III.—*Resistance Metals.*

German Silver Wire.	Manganin Wire.	Size.
Ohms per lb., bare.	Approximate ohms per lb., bare.	Birmingham. W.G.
.97727283	1.7	14
1.7243168	3.0	15
2.5982120	4.6	16
4.0984280	7.2	17
8.045352	14.2	18
14.905	26.3	19
30.9065	55	20
44.231	78	21
75.459	133	22
118.733	210	23
197.987	349	24
289.873	512	25
441.813	780	26
707.699	1249	27
1207.305	2131	28
1623.894	2866	29
2236.68	3948	30
2667.3	4708	31
3186.34	5624	32
4283.85	7561	33
5727.55	10110	34
8143.0	14372	35
11977.2	21440	36
17406.8	30721	37
21815.8	38505	38
29614.3	52270	39
41223.0	72760	40
74639.5	131730	41
182117.6	321450	42
601774.2	1062100	43

Table IV.—"*Rheostene*" *Wire.*

Particulars of Resistance, Current Capacity, &c.

S.W.G.	Ohms at 15.5° C.	50° C. Rise in Temperature.			100° C. Rise in Temperature.			150° C. Rise in Temperature.		
		Ohms per yard at 65.5° C.	Amperes giving a rise of 50° C.	Watts consumed per yard.	Ohms per yard at 115.5° C.	Amperes giving a rise of 100° C.	Watts consumed per yard.	Ohms per yard at 165.5° C.	Amperes giving a rise of 150° C.	Watts consumed per yard.
8	.0541	.0571	20.1	23.1	.0601	33.0	65.5	.0631	39.0	96.0
9	.0669	.0706	17.8	22.4	.0743	28.1	58.6	.0780	34.0	90.0
10	.0845	.0890	15.1	20.3	.0938	22.8	48.75	.0984	27.8	76.0
11	.1024	.1080	13.2	18.8	.1137	19.6	43.70	.119	23.7	66.7
12	.1290	.136	11.3	17.4	.143	16.6	39.35	.150	20.2	61.2
13	.1646	.174	9.4	15.4	.183	13.7	34.35	.192	16.6	52.8
14	.2180	.230	7.6	13.3	.242	11.6	32.55	.254	13.9	49.0
15	.2670	.282	6.7	12.7	.296	10.0	29.60	.311	12.1	45.5
16	.3382	.357	5.7	11.6	.377	8.60	27.90	.394	10.5	43.4
17	.4406	.465	4.7	10.3	.489	7.20	25.4	.513	8.8	39.7
18	.6008	.634	4.0	10.15	.667	5.93	23.5	.700	7.35	37.8
19	.8677	.915	3.2	9.38	.963	4.80	22.2	1.01	5.91	35.3
20	1.0680	1.13	2.84	9.12	.119	4.25	21.5	1.24	5.25	34.2
21	1.3528	1.43	2.5	8.94	1.50	3.75	21.1	1.59	4.61	33.8

Useful Tables

Useful Formulæ, &c.

Pure copper weighs 555 lbs. per cubic foot.

The Specific Gravity of pure annealed copper wire is about 8.9 at 60° Fahr., Log. .94390.

The Specific Resistance of pure copper, or the resistance of a cubic centimetre at 0° C. or 32° Fahr. = .000001642 ohm., Log. $\bar{6}$.2153732, and of a cubic inch at 32° Fahr. or 0° C. = .00000064 ohm., Log. $\bar{7}$.8061800.

The resistance of pure copper varies with the temperature .215 per cent. per degree Fahr. or .387 per cent. per degree Centigrade.

Stranded Wires.—A stranded conductor of given length is of greater weight than an equal length of the same number and size of wires unstranded, and also has a greater area than the same number unstranded.

1 Mil.	=	.001 inch.
Sectional area in square inches	=	d^2 inches × .7854.
„ circular mils.	=	d_2 in mils.
.7854 = Log. $\bar{1}$.8950909.		3.1416 = Log. .4971509.

To convert—

Mils. to millimetres	multiply by	.0253995 4.
Inches to millimetres	„	25.39954.
Square inches to square millimetres	„	645.137.
Cubic inches to cubic millimetres	„	16386.18.
Yards to metres	„	.914383.
Miles to kilometres	„	1.6093.
Pounds to kilogrammes	„	.45359.
Millimetres to mils.	„	39.3708.
Millimetres to inches	„	.0393708.
Square millimetres to square inches	„	.00155006.
Cubic millimetres to cubic inches	„	.000061027.
Metres to yards	„	1.09363.
Kilometres to miles	„	.62138.
Kilogrammes to pounds	„	2.204621.

The resistance of any pure copper wire at 60° Fahr. or 15.5° Cent.

Ohms per mile = .0430597564 divided by area in square inches.

Ohms per yard = .00002446577 divided by area in square inches.

Ohms per kilometre = 17.260152 divided by area in square m/m.

The weight in lbs. per mile of any pure copper wire—*

lbs. per mile = area in square inches	multiplied by	20350.
lbs. per yard = area in square inches	„	11.5625.
Kilogrammes per kilometre = area in square m/m	„	8.89214.

* A wire d. mils in diameter weighs $\frac{d_2}{62.57}$ lbs. per mile.

Table V.—*Relative Resistances and Weights of Various Metals and Alloys as compared with Pure Copper at* 60° *Fahr. or* 15.5° *Cent.*

Metal.	Relative Resistance.	Relative Weight.	Variation of Resistance for Temperature.	
			Fahr.	Cent.
Iron	6.356	.8666	.388 %	.7 %
German Silver	12.437	.9549	.024 %	.044 %
Platinum Silver (2 oz. Ag. 1 oz. Pt.)	14.465	1.423	.017 %	.031 %
Manganin (manganese, nickel, copper) approx. . . .	24.85	.97	.000025	.000045
Rheostene	44.5	.917	.00588	0.11

TABLE VI.—*Details of Conductors.*

Showing Dimensions, Capacity, Resistance, and Weight.

Size.	Amperes at 1000 per square inch at above ratio, Loss = approx. 2½ volts per 100 yards.	Amperes at I.E.E. Standard.	Diameter.		Area.		Standard Resistance at 60° Fahr.			Maximum Resistance Allowable per Mile, viz., 2 per cent. above Standard.	Standard Weight.		Minimum Weight Allowable, viz., 2 per cent. below Standard Pound per Mile.	Size.
S.W.G.			Inches.	Milli-metres.	Square Inches.	Square Milli-metres.	Ohms per 1000 Yards.	Ohms per Mile.	Ohms per Kilo metre.		Pounds per 1000 Yards.	Pounds per Mile.		S.W.G.
22	0.6158	1.7	.028	0.7112	.0006158	.3973	39.05	68.72	42.70	70.09	7.120	12.53	12.28	22
21	0.8042	2.2	.032	0.8128	.0008042	.5188	29.90	52.62	32.70	53.67	9.301	16.37	16.04	21
20	1.0179	2.6	.036	0.9144	.001018	.6567	23.62	41.57	25.83	42.40	11.77	20.72	20.31	20
19	1.2566	3.2	.040	1.016	.001257	.8109	19.13	33 67	20.92	34.34	14.53	25.58	25.07	19
18	1.8096	4.2	.048	1.219	.001810	1.168	13.28	23.38	14.53	23.85	20.93	36.83	36.09	18
17	2.4630	5.4	.056	1.422	.002463	1.589	9.762	17.18	10.68	17.52	28.48	50.12	49.12	17
16	3.2170	6.8	.064	1.626	.003217	2.075	7.478	13.16	8.178	13.42	37.20	65.47	64.16	16
15	4.0715	8.2	.072	1.829	.004072	2.627	5.904	10.39	6.456	10.60	47.09	82.87	81.21	15
14	5.0265	9.8	.080	2.032	.005027	3.243	4.784	8.419	5.232	8.587	58.13	102.3	101.3	14
13	6.6476	12.4	.092	2.337	.006648	4.289	3.617	6.366	3.956	6.493	76.88	135.3	132.6	13
12	8.4949	15.0	.104	2.642	.008495	5.480	2.831	4.982	3.096	5.082	98.24	172.9	169.4	12
11	10.568	18.0	.116	2.946	.01057	6.819	2.275	4.004	2.488	4.084	122.2	215.1	210.8	11
10	12.868	21.0	.128	3.251	.01287	8.303	1.868	3.228	2.043	3.354	148.8	261.9	256.7	10
9	16.286	27.0	.144	3.658	.01629	10.51	1.476	2.598	1.614	2.650	188.4	331.5	324.9	9
8	20.106	31.0	.160	4.064	.02011	12.97	1.195	2.104	1.307	2.146	232.5	409.2	401.0	8

CHAPTER III

PRACTICAL ELECTRICAL MEASUREMENT—VOLT AND AMMETERS

In this chapter practical electrical measurement forms the main theme, with details of the instruments, ammeters and voltmeters.

Only by measurement can much be learned about electricity; not being a substance which we can handle, we are compelled to examine it by measuring and observing its effects.

The electrometer renders the effects of pressure and charges of electricity visible, and the Branly tube detects, and renders audible and visible, evidence of electro-magnetic induction currents of exceedingly small magnitudes, thus making wireless telegraphy possible. The magnetic needle and electro-magnetic coil and the electro-magnet show us the effects of dynamic electricity; and the telephone is another exceedingly sensitive instrument in which very slight electrical effects can be detected by the ear. The electrician's instruments are many and diverse, but when we come to reduce them to a series of classes, they appear very simple and few, and there is ample evidence of a tendency towards a line of standard types of measuring instruments. We require to measure volts, E.M.F., and P.D. (pressures); also current alternating and continuous; also power or watts alternating and continuous, ohmic resistances, impedance, horse-power, and efficiencies.

The instruments for measuring electric pressures are based upon the following principles:—

1. The electrical condenser, in which an electrified movable plate, vane, or needle is attracted by a fixed plate or plates—the gold-leaf electroscope being the simplest and earliest form. Instruments on this principle are called static instruments.

2. The expansion of a wire heated by the current produced by applying the electric pressure to its ends, hot-wire instruments, and instruments in which air is expanded by the heat produced.

3. The electro-magnetic effects of coils on coils of wire, of coils on iron cores, coils on magnets and magnetic needles.

This last class is exceedingly numerous. It includes the cheap instruments demanded by the contractors for installation work, who require an instrument not necessarily absolutely correct, but as a guide or indicator as to the volts and amperes in the circuits in small installations and isolated plants. They range in price from

fifteen shillings to two guineas; are of exceedingly simple construction, especially when to be used on a steady current glow-lamp circuit. For motor work and arc-lamp circuits dead-beat instruments are necessary. In cheap instruments this is furnished by using an oil dash-pot to steady the needle. To this same class belongs also the fine accurate Kelvin balances, the Siemens dynamometer, the moving coil instruments on De Arsenvall's types, the ballistic and reflecting galvanometers.

The second types are eminently suited for ordinary engineering purposes, and have a considerable advantage in being correct on either continuous or alternating circuits, are dead beat, not affected by magnetic fields, and altogether for everyday shop-work are admirable types of instruments.

The first class of instruments are only for pressure measurements, are accurate on either alternating or continuous pressures, and have no appreciable errors due to heating or to external magnets. This type of instrument has been sedulously cultivated by Lord Kelvin.

In the foregoing classification the classes are distinguished by the nature of the moving forces—static, dynamic, and thermic. But we must further subdivide them according to the nature of the controlling forces; the electric forces acting must be opposed or controlled by some other forces in all measurements. Thus we have instruments in which weights oppose the motion produced by the electric forces, instruments in which springs oppose the motion, and torsion wires, and magnets, and the earth's directive magnetic force. Thus we get gravity, spring, torsion, and magnetically controlled instruments.

Controlling or opposing weights are used in two ways—weights swinging on an arm describing an arc of a circle, and weights in which the force required to lift the weight round the circle is approximately as the sine of the angle of deflection of the weight; and weights can be used in a balance to balance the electric forces.

Springs of all kinds are used—flat springs, spiral springs, hair springs, coach springs, all opposing the electric forces proportionally to the degree of deflection, stretching, or torsion; then we have the torsion wire, which practically is a spring.

In magnetically controlled instruments we have permanent steel magnets producing a pull or directive force on a needle, or opposing the motion of a coil, and in delicate instruments we use the earth's magnetic field to oppose the forces to be measured; and for the most refined measurements we employ astatic needles, so that the earth's controlling power is reduced to a very small value.

In Fig. 49 we have an example of a balance by which we can measure by means of a weight in which two fixed coils carry a

known current; while a movable coil between them carries the current to be measured, entering by mercury cups, the upper fixed coil repels and the lower coil attracts the movable coil, so that weights must be added to the scale pan until balance is obtained, when the weights will be proportional to the current in the movable coil, with a constant current in the fixed coils.

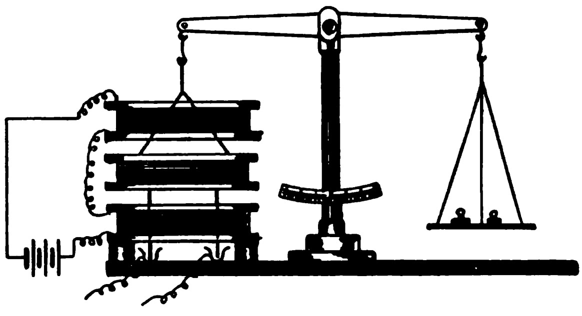


Fig. 49

In Fig. 50 we have an example of the weight moving in an arc of a circle and attached to the arbor of a meter.

And Fig. 51 is a diagram illustrating the laws of this moving weight. Suppose we have a pulley P, over which a cord hangs carrying two equal weights A and B, just enough to keep the cord taut; a third weight is hung on the periphery of the pulley at *e;* it is obvious that the weights will naturally take up the positions shown by the black lines, C being perpendicular to the centre. If we add weight to B, C will be gradually lifted, and the thread T carrying it will travel along the scale S, and we will find that when thread T coincides with T_1 that we have added just the weight equal to C to the scale pan on B. But the thread T does not travel across the scale at the same rate for equal weights added. At the start a small weight sends it along a long distance, while as the weight rises it takes more and more added weight to move it; the movement is as the sine of the angle of deflection. If we draw lines at equal angles apart from the centre to the circumference, and drop perpendiculars to a scale as at S, the divisions

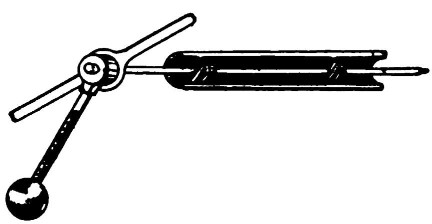


Fig. 50

thus obtained will give the distances moved through by the thread T for equal increments of weight. The resistance of the weight to the moving force is very weak at first, and gradually increases up to the full weight of C. As the divisions become very close on the scale after passing 50° from the perpendicular, the range is limited to about 60° deflection in all instruments using a controlling weight. Fig. 52 is an illustration of an instrument for testing the torsional elasticity of wires. The wire is caught in a clamp at the upper end, and stretched by a lead ball at the lower end carrying a pointer over a

circle graduated; the force required to twist the wire so that the needle passes to an angle—*the angle of torsion*—is the force of torsion.

If twisted and let go the pointer oscillates synchronously, that is, like a pendulum; the swings decrease in angular distance but increase in rapidity until they die out. The laws of torsion found in this way by coloumb are:—

1. The angle of torsion is proportional to the force of torsion applied.

2. With same force of torsion, and with wires of same diameter, the angles of torsion are proportional to the lengths of the wire.

3. The same force of torsion being applied to wires of same length, the angles of torsion are inversely proportional to the fourth power of the diameters.

The laws of torsion are given in the formula—

$$W = \frac{F\,l}{r^4} \times K, \qquad (1)$$

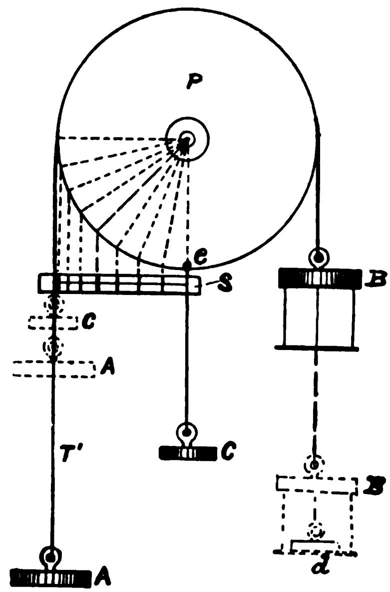


Fig. 51

where K is a constant for each different material; *W*, the angle of torsion; F, the applied force; *l*, the length of the wire; *r*, its diameter. In lead, for instance, K is about equal to zero, very high in all hard metals, phosphor bronze, steel, hard drawn iron, silver, glass, and highest of all in quartz fibre—a fibre ingeniously produced by Prof. Boys by melting a bead of quartz, attaching it to the feather end of an arrow, which is shot from a bow at the moment of fusion. The arrow draws out the melted quartz into a long fine filament during its flight.


Fig. 52

In practice steel wires or phosphor bronze wires are used.

A spiral spring when drawn out follows the same laws, for the wire of which it is made is subject to torsion when the spring is extended.

A spring like the main-spring and hair-spring of a watch is

subject to flexure, like a straight spring bent over. The laws of flexure springs are represented in the formula—

$$E = \frac{w\,l^3}{h\,b^3\,u}, \qquad (2)$$

where w is the force; l, the length of the spring from the point of the application of the force to the grip; b, its breadth; h, its thickness; and u, its modulus of elasticity; and E is the amount of flexure.

FIG. 53 Spring of Ayrton & Perry's Ammeter

A peculiar spring, invented by Messrs. Ayrton & Perry for measuring purposes, is made up of a hard metal ribbon wound into a spiral. If such a spring is fixed at one end, and extended by force applied to the other end, it unwinds, and a pointer on the free end describes a circle, the angle of rotation being proportional to the force applied. Fig. 53 represents a piece of this spring, and Fig. 54 a diagram of an instrument with such a spring carrying at its lower end an iron core dipping into a solenoid; on passing current the core is pulled down and the spring unwinds in proportion to the pull, and moves the pointer to a proportionate angle. Such instruments, invented and designed by Messrs. Ayrton and Perry, are very accurate and have a fairly long range. A carbon ribbon twisted up in the same shape, and carrying a pointer, will untwist on being heated by a current passed through the spiral, and can therefore be employed on the hot-wire principle.

FIG. 54.—Ayrton and Perry's Spring

In Figs. 55 and 56 we have examples of the flexure spring control. The spring is like the hair-spring of a watch, and brings the needle back to zero; a coil C has an arbor centred on jewels, carrying the thin piece of soft iron B and the pointer, and one end of the hair-spring is fixed to this arbor, so that the spring resists the torque on the shaft or arbor; when current passes in the coil the thin slip of iron B on the arbor is repelled by the slip A fixed in the coil with a force in some proportion to the current, and against the force of the spring. By this action the travel of the pointer indicates the current. On this principle many manufacturers make instruments; in fact, it is the favourite type for cheap indicators so numerously required in practice. Its chief fault as a measuring apparatus is one which is common to all instruments in which soft iron is used—it has a "hysteresis" error. This may be explained here as applied to instruments. Soft iron

when once magnetised by the coil does not lose its magnetism instantly when the current is cut off, neither does its magnetic strength fall in proportion to the fall in current strength in the coil; it keeps a small proportion of magnetism.

This may be better understood by an example. Suppose we are using an ammeter in which two soft-iron plates repel each other, as in Figs. 55 and 56, and we have passed 12 amperes through it for a time. We now reduce the current till the pointer reads 10 amperes steadily; let the meter be switched off for a moment, and switched on again by a short-circuiting plug, without disturbing the current, we will find that the pointer does not come back to 10 amperes again, and the difference is due to the hysteresis error of the instrument. For in the first place we reduced the current until the pointer read 10; but the iron plates, retaining the magnetism, did not fall in proportion to the fall in current, so that to bring the pointer from a higher to a lower reading we had to reduce the current more than was indicated by the pointer to bring it to 10.

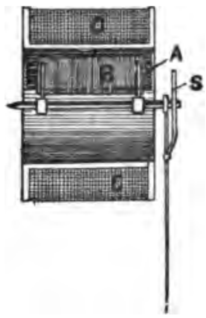


Fig. 55

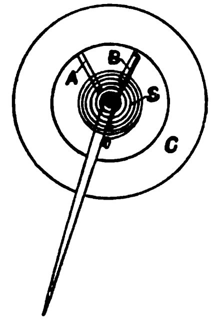


Fig. 56

In the second place, we reduced the magnetism by the switching out, and upon switching in again the magnetism of the iron rose to its correct value, and indicated the true current to be 9.5, for instance. In soft-iron instruments this hysteresis error comes in on a falling current reading; hence if we take a series of readings from zero, going up step by step to full load, the readings will be correct, but if we take readings from full load step by step downwards the readings will be wrong. However, by making the iron plates very thin and very soft—of the thinnest annealed ferrotype plate—this error is not serious in an instrument to be used as an indicator in a common installation. And it is always easy to test it in the above way, by first running up the pointer to a large reading, then gently reduce the current 2 or 3 amperes, then plug it out and in again; the difference in

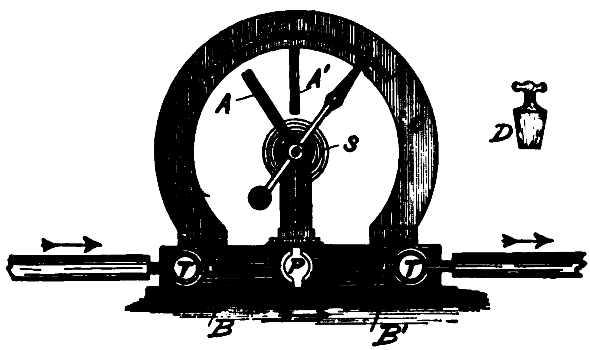


Fig. 57

readings before plugging out and after plugging in again is a measure of the hysteresis error.

This short circuiting plugging out and in is a method of cutting off current from an ammeter only, and must never be attempted on a voltmeter. Fig. 57 illustrates the method by a diagram: C is a copper coil in this case of one turn in the ammeter, attached to two terminal blocks B B′; these blocks can be coupled by inserting a brass plug D in the conical hole P between them, so that nearly all the current goes straight through, and thus by a by-pass carries it without going round C. It will be obvious that by this device we can cut the current off from an ammeter without interfering with the current to any appreciable extent in circuits on 110 volts and upwards.

This hysteresis error differs, of course, in different instruments with soft iron. The design has a good deal to do with its amount, the shorter and thinner the strip the less hysteresis. In the oblate spheroid instrument it is also apparent, and in instruments where a soft-iron wire attracts or is attracted into solenoids. It can be got rid of only by using extremely thin soft wires in powerful coils, so that the wire is practically over-saturated at very small loads. In commercial instruments it need have no appreciable value, this error; for an ammeter used as an indicator need not in most cases read down below one twentieth of the full load reading, while voltmeters usually read only a few degrees on either side of a fixed value, and if correct at that value are correct for all practical purposes.

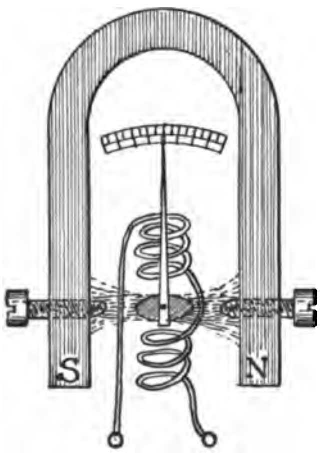


Fig. 58

Springs and torsion wires have been objected to on the ground that they may alter in time and so become inaccurate; but long experience proves that if properly proportioned to the work to be done, any alteration is so minute as to be negligible. A torsion wire especially, if not twisted too much, is practically constant for years and years.

A bifilar suspension acts also in the same way as a torsion wire, but there is no strain on the filaments except a tensile strain.

The tangent galvanometer is an example of the control by the earth's magnetic field, and the illustration (Fig. 58) shows an instrument by Ayrton & Perry, with a permanent magnet control, in which an oblate spheroid suspended between the poles turns with its longest axis from pole to pole. Two coils with their axis at right angles to

the magnetic field are the measuring coils: these coils tend to twist the spheroid into line with their own axis. The side screws are for adjusting the field.

In the moving coil instruments, so common now, we have three elements to deal with: the moving coil carrying the current to be measured, the magnetic field in which it moves, and the torsion wire or spring or weight against which the forces are measured. The moving coil is in a uniform strong magnetic field. Fig. 59 is a diagram of this type of instrument: an iron stationary core is between the poles, leaving space in which the field is concentrated for the coil to move freely; the magnets are of steel, and as powerful as possible. In Fig. 59, which is only a diagram, the central cylinder is of softest iron; the magnet is usually built up of a number of thin steel lamina. Such instruments are very sensitive, but all permanent magnet instruments are limited to continuous pressure measurements only.

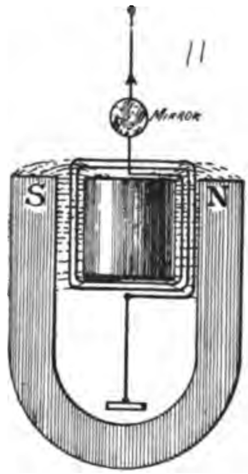


FIG. 59

Hot-wire instruments, like soft-iron instruments, have a somewhat limited range; the heat is generated in the wire in proportion to the square of the current, or as C × E, C being the current and E the P.D. at the ends of the wire. Hence an instrument for, say, 120 volts reads correctly down to about 20 volts only, as the heating at the low pressure becomes very feeble on a wire long enough to stand 120 volts. Properly made and used hot-wire instruments have no serious errors; they are dead beat, and are equally correct on continuous or alternating circuits for measuring current and pressure.

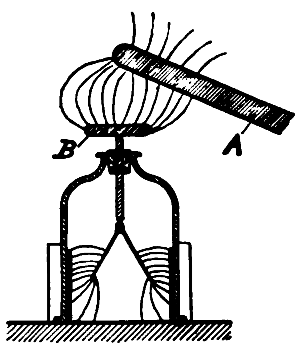


FIG. 60

Electrostatic instruments were the earliest of all electrical measuring apparatus. The old gold-leaf electroscope was a high-pressure voltmeter, modifications of which are now the most successful high-pressure voltmeters of to-day. In Fig. 60 we have the simple electroscope, containing two gold leaves and two earth-connected upright rods, to which the leaves are attracted when electrified. The lines of force are shown: these lines are like stretched rubber filaments, tending to contract and draw the leaves to the nearest objects, the rods, in the induction circuit; but the pull due to the force is resisted by the weight of the gold leaves, and the angle of deflection is roughly an indication of the electric pressure

set up between the electrified stick A and the plate of the electroscope B.

A better design is shown in **Fig. 61**, wherein there is one leaf

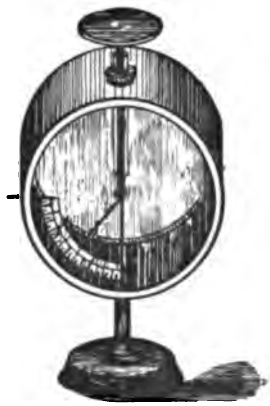


FIG. 61.—Prof. Jamieson's Gold-Leaf Electrometer.

FIG. 62—Lord Kelvin's Gold-Leaf Electrometer

laid against a fixed plate, and a scale showing the deflections of the leaf. The cylinder is of cardboard or ebonite, and an earth-connected strip of tinfoil or metal should be fixed on the outside under the scale to attract the leaf. A still more perfect instrument is shown at Fig. 62, designed by Lord Kelvin; the case is a quadrant and the leaf very highly insulated, with an accurately divided and calibrated scale from 500 to 5000 volts. Fig. 63 is a further development of this type of voltmeter to measure up to 100,000 volts. In this instrument a movable plate V is attracted by a highly insulated plate B connected to the body whose pressure is to be measured, and the attraction is measured by weights N on the beam; the lines of force tend to shorten, and hence the suspended plate is drawn downwards. This same principle is utilised in the electrometer

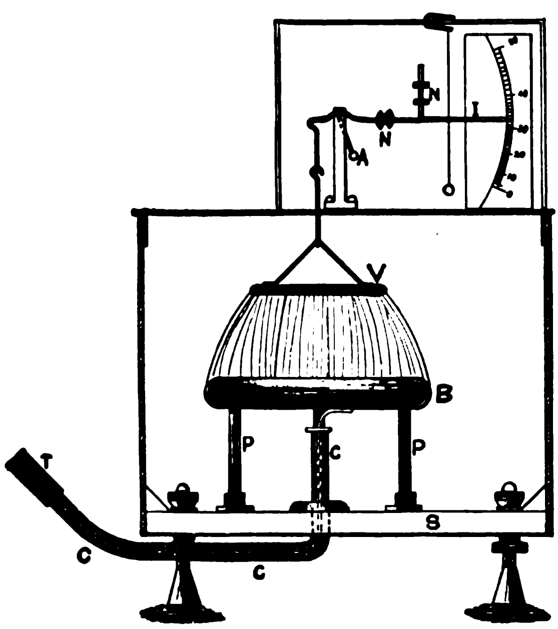


FIG. 63—Lord Kelvin's Electrostatic Balance, showing lines of force between plates

shown in Fig. 64, an attracted disc electrometer diagram: the disc is hung on a beam balanced by a weight; the disc is sur-

FIG. 64

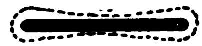


FIG. 65

FIG. 66

rounded by a ring to guard it from induction from objects around it. These actions should always be explained by a diagram of the lines of force. In Fig. 65 a plate or disc is shown edge view, and is usually represented to have a charge much denser at the edge, as shown by the dotted outline; this, however, does not fully illustrate the facts. Fig. 66 shows the facts in this case: the bulk of the lines of force stream up to the upper disc; but towards the edges they spring aside, so that the density is only uniform in the central portion. It will be obvious that both these instruments are simply air

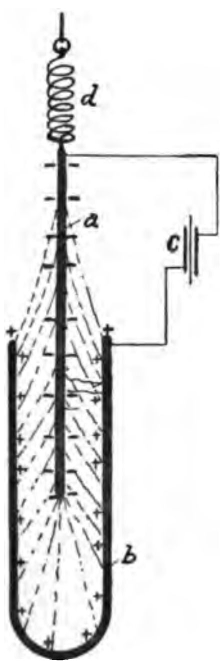


FIG. 67

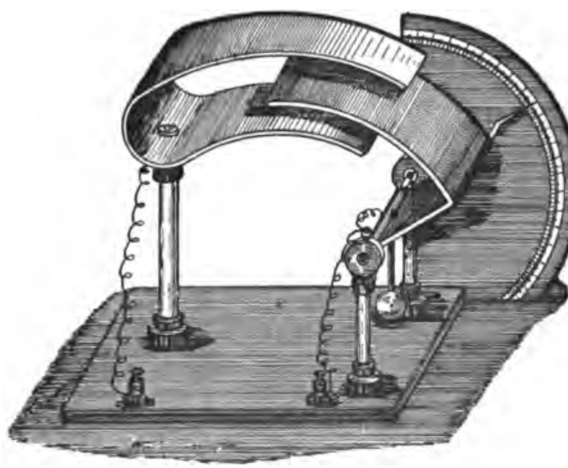


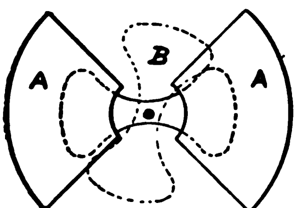
FIG. 68

condensers, the lower plate being the one coating and the upper plate the other coating, the air the dielectric; the one coating is made movable so that the force attracting it can be measured. Following this principle, many designs can be made. Fig. 67 shows a condenser with the inner plate movable and suspended

on a spring. On charging the outer bent plate the movable plate is sucked into the outer one, the lines of force being distended, as shown ; pull downwards so as to shorten them. On this principle Messrs. Ayrton & Mather make a voltmeter, shown in diagram, Fig. 68. The movable coating or plate is carried on an arbor, and is bent to the curve described by the radial support ; the outer charged coating is also bent to the same centre. On charging the central plate is pulled inwards, the pull being resisted by the weight hung on the arbor, as shown in the figure.

Lord Kelvin, who has made this class of instrument peculiarly his own, and who originated their practical application, introduced

Fig. 69



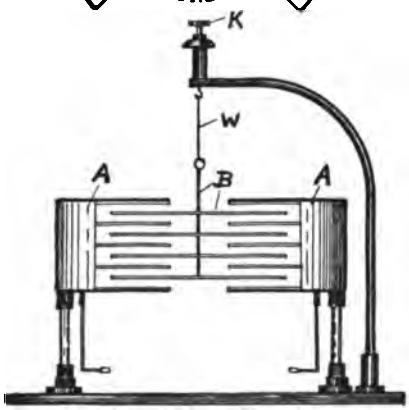


Fig. 70

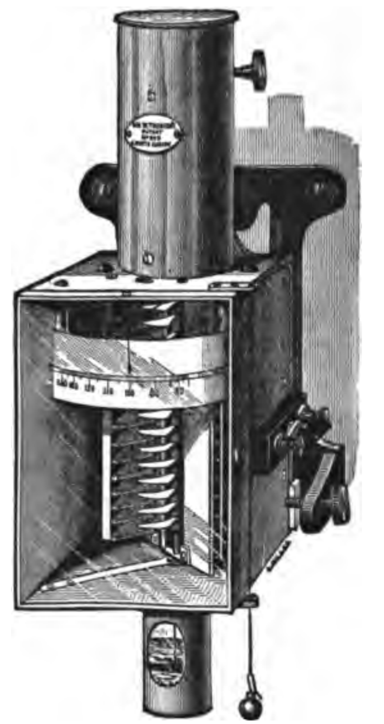


Fig. 71.—Kelvin's Multicellular Voltmeter

the multicellular type shown in diagram, Figs. 69 and 70. Fig. 69 shows the well-known electrometer cell with two quadrants removed. Normally a torsion wire maintains the paddle B in the position shown by dotted line, and when the paddle B is put to one pole + and A A, the quadrants to the other pole, the paddle is drawn into the position shown by the full lines against the torsion of the spring or wire. One paddle and quadrant has but a feeble pull at ordinary working electric pressures ; the pull can be multiplied to any required extent by multiplying the paddles and quadrants. This Lord Kelvin does by the construction shown

in Fig. 70 in elevation. A number of paddles are strung on one shaft and hung by a torsion wire, W; these work into a number of quadrants, A A. By this means a condenser voltmeter can be made to read as low as 50 volts and over a long enough range for all practical purposes. Fig. 71 illustrates the complete instrument, vertical pattern. The paddles and quadrants are clearly seen, with the oil dash-pot and arrangements for easily and accurately levelling and plumbing the instrument on a switchboard.

These condenser instruments are the most perfect types of voltmeters; they consume no current, have no magnetic nor temperature errors, are equally correct on continuous or alternating currents, are not affected by external magnetic disturbances. As standard voltmeters they approach perfection nearer than any other type known.

Figs. 55 and 56 represent the cheap form of magnetic spring or gravity-controlled meters. They have a large sale, principally for small installations, motors, and lamps; for motor work they require a dash-pot to steady the needle. Expensive instruments are not required, and cannot be afforded in many installations where numerous instruments are desirable. In every case of the adoption of electro-motors for driving, the owners like to know what each motor is doing, and nothing is more pleasing than an ammeter and voltmeter on each motor; but at present prices that desirable addition is, except in the case of large motors, not possible. The author had an installation of over 60 motors, ranging from ½ to 10 horse-power each, the majority between 1 and 3 horse-power; the cheapest instruments to be obtained would have cost over £150 for the lot.

An instrument based on the hydrometer principle has recently been brought out as a cheap instrument. It consists of a glass tube containing a saturated solution of a special salt which has a constant density. In this solution is sunk a hydrometer which carries a thin wire of iron; over the top of the tube is fitted a solenoid, so that the iron wire just enters this solenoid; on the current passing the hydrometer is pulled up, and the extent to which it rises is proportional to the current in the solenoid, A scale and an index, consisting of a black and white band on the hydrometer, indicates its position, the division line between the black and white band being the index line. Fig. 72 shows the glass tube containing the hydrometer and iron wire, and Fig. 73 the complete instrument. Essentially, this instrument is a coil and iron core instrument acting against a weight.

An old instrument on this principle had a considerable sale at one time. About fourteen years ago it was brought out by Lalande; it is shown in Fig. 74. In this case the hydrometer floated high in the liquid, which I believe was oil. It had some

faults: a short range—which, of course, is not a fault in most installation work—a hysteresis error, and an error due to temperature altering the density of the liquid. These faults seem to have been overcome in the Atkinson meter. The idea is still older, for a hydrometer meter was described about fifty years ago by one Iremonger.

Lord Kelvin has brought out an accurate form of coil and iron core meter with weight reaction. It is shown in Figs. 75, 76, and 77.

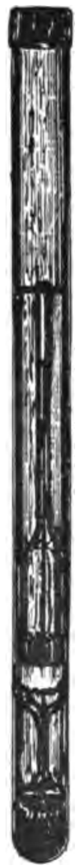


FIG. 72

FIG. 73.—Atkinson Meter

FIG. 74

Fig. 75 is a complete front view, 76 an outline front view, and 77 a side view. The wire is hung by a thread over an aluminium quadrant, and balanced by the weight threaded on the horizontal wire on the tail of the quadrant; the pull of solenoid on the wire is opposed by the weight on the down-hanging vertical wire. The principles of these solenoid and core instruments are worth considering. In Fig. 78 we have a diagram of a solenoid and wire. To get rid of hysteresis errors, and make the pull on wire equally

increase for equal increments of current, the wire must be magnetically saturated; hence it is no use commencing the scale at a current below that which saturates the wire. In the diagram we will suppose the current to be sufficient to saturate the wire, which is one millimetre sectional area. If it is pure soft iron the total flux will then be 2000 C.G.S. lines of force passing through the magnetic equator of the wire *a, b;* these 2000 lines will cut the solenoid wires carrying the current; it is this field current carried by the wire upon which the pull depends. If the wire is long and thin, this field is constant; hence any variations in the current

Fig. 75

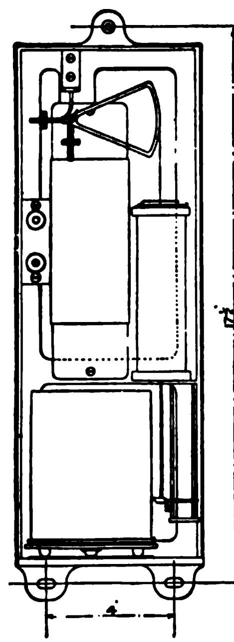


Fig. 76

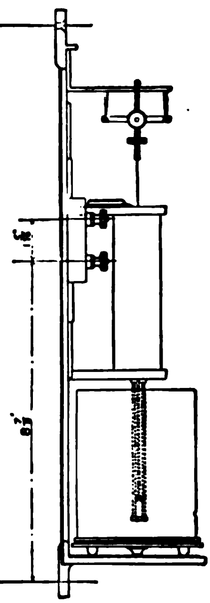


Fig. 77

in the coils will proportionally vary the pull, and its strength could be calculated if we could find the number of convolutions and their ampere-turns cut by the flux of 2000 lines; but this is difficult to find, as the flux spreads out in curves. There is, of course, a strong field due to the coil itself riming axially through the coil; but that field may be considered only as the magnetising field for the wire, and may be neglected in calculating the pull, as that is given by the field of wire, as shown, and the ampere-turns cut by that field.

The moving coil instruments are those in which the core is fixed and the coil moves, referred to before in Fig. 59. In this case we can calculate the torque exactly, for the field can be uniform

and concentrated. A common strength of field induction in these instruments is 1500 per square centimetre. In a field of this strength the pull on the coil can be calculated by measuring the length of wire under the induction in feet. Suppose the vertical sides of the coil in Fig. 59 to measure 1 inch each average length of wire, and say there are 200 turns, that is, 400 inches under the induction of B = 1500. And suppose further the coil carries 0.05 ampere, then by formula $P = \frac{C\,B}{98{,}100}$ we can find the pull, wherein P is the drag in lbs. per foot length of wire, and C the current in amperes, B the induction in C.G.S. lines per sqr. cm., hence

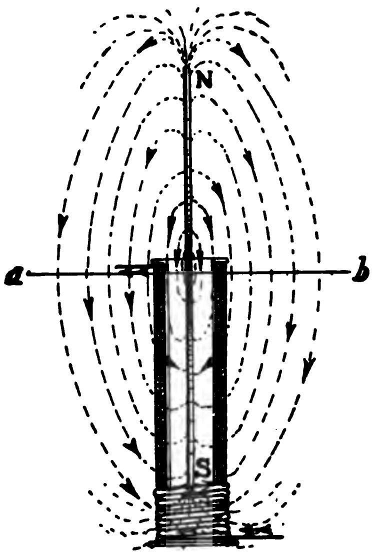


FIG. 78

$$\frac{0.05 \times 1500}{98{,}100} = 0.015 \text{ lbs.}$$

Moving coil instruments are found to be reliable, accurate, and dead beat. They are usually, when made for current measurement, wound as voltmeters, and put in shunt with a resistance, as explained before in Chapter II. The resistance is made up of substantial construction, with strong terminals for coupling in the current in series with the load. These terminals should be made for soldering the wires or cables into them. As a rule, they are made for bolting or pinching into the wire. An illustration of this resistance is here shown in Fig. 79. It consists of thin plates of high resistance metal, the plates giving large cooling surfaces. The terminals TT are massive, so that they also tend to cool; but in some cases, owing to bad contact between the cables and terminals, the resistance is heated, and then the voltmeter reads wrong. Hence much care must be taken in using this type of instrument to see that perfect contact is made to the terminals.

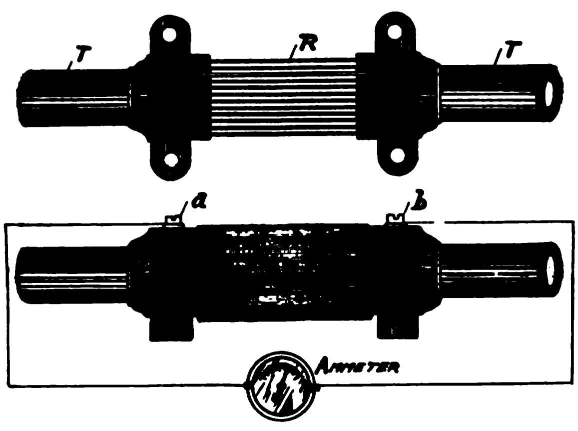
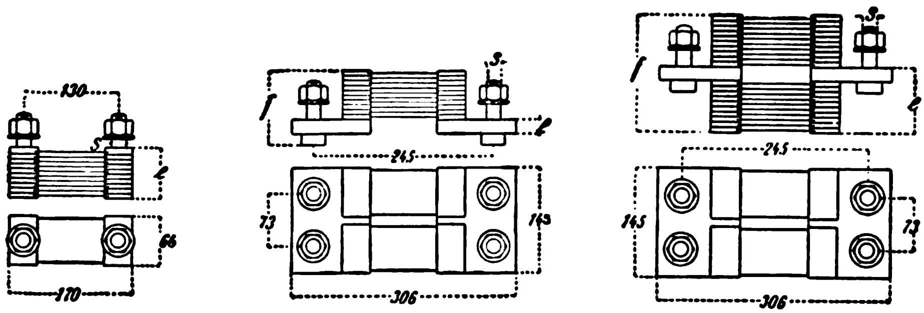


FIG. 79

Fig. 80 illustrates the Siemens resistances for their moving coil instruments. No. 1 is for currents from 75 to 1000 amperes. It has one tier of plates, and two massive bolts and nuts for connections. No. 2 has two tiers of plates, for currents from 1200 to 2000 amperes, and four massive bolts and nuts for connections; and No. 3 has four sets of plates, for currents from 2500 to 4000 amperes.

This shunted moving coil ammeter is of great practical value for large currents, for to make ammeters of long range to carry currents over, say, 500 amperes, and to connect them up on a switchboard, is no easy matter, while to make them portable for currents of large value is almost impossible.

This system is, however, not practicable except in high voltage circuits (circuits from 100 volts upwards), for if put into low-pressure circuits of 5 to 10 volts used for chemical work, the resistance drops the whole pressure and current appreciably. This point should be



No. 1 No. 2 No. 3

FIG. 80

borne in mind in using ammeters either on this system or any other, that their resistance is an important question, and in specifications a test should be made of the drop in pressure across the terminals at full load in all large instruments. The moving coil instruments, like the coil and iron core instruments, are equally applicable for ammeters or voltmeters, according to the winding of the coils; but the moving coil instrument with the permanent magnet is not applicable to alternating current measurement.

The moving coil instruments of Siemens Brothers are exceedingly fine and accurate; the permanent magnet A is shown in Fig. 81, and B shows the moving coil and pointer mounted in a plug for insertion between the magnet poles.

The electrostatic or condenser instruments are essentially voltmeters, and applicable to either continuous or alternating currents, especially of high pressure. And the hot-wire instruments are also applicable to either alternating or continuous currents, and can be used for ammeters or voltmeters. The well-known Cardew voltmeter is illustrated here in Fig. 82. A fine wire is strung up and

down four times over three pulleys, as shown, making about 10 feet or 12 feet of wire; the two ends are fixed, so that a spring pulling on the lower pulley draws it down when the wire expands, due to the heat generated in it by the current; the cord connecting the

A B

FIG. 81.—Siemens Brothers' Moving Coil

wire with the spring goes round a pulley and so turns the pointer. Fig. 83 shows the Edison-Swan type of this instrument. The range of readings on the dial can be doubled by a duplicate wire in a tube (Fig. 84) being connected in series with the voltmeter.

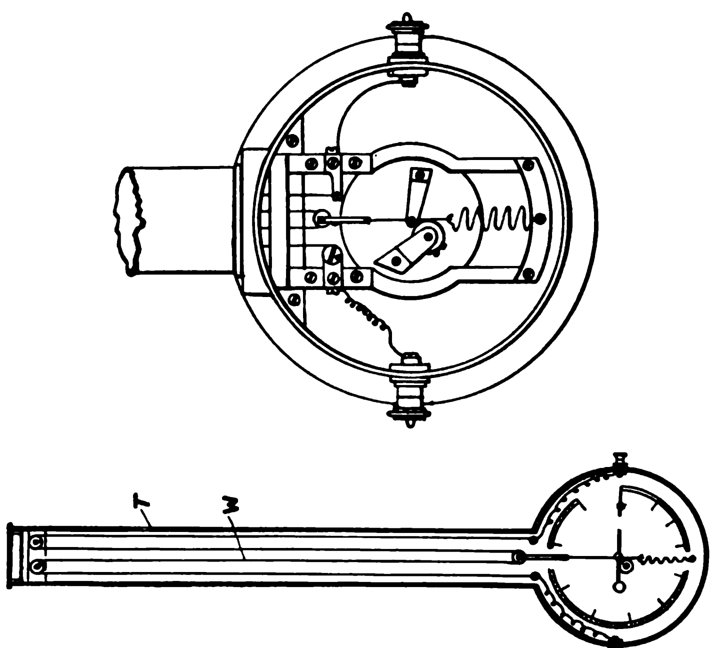


FIG. 82.—Cardew's Hot-Wire Voltmeter

It is used principally as a voltmeter, but might also be used as an ammeter by coupling across a resistance in the current circuit, if it can be made to work at very low voltages. The instrument is very satisfactory for testing arc lamps and motors of all kinds;

when laid horizontally, it is dead beat and exceedingly sensitive, has no magnetic nor hysteresis errors, and is not affected by magnetic fields.

Fig. 85 illustrates another form of hot-wire instrument invented by Major Holden. In the Cardew instrument we measure the linear

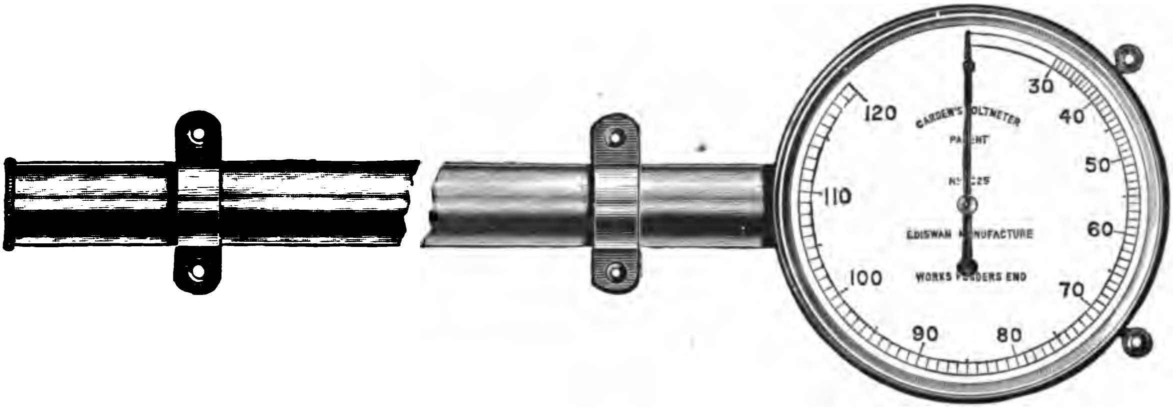


Fig. 83

extension of the wire, which is never a great amount in a short length; in the Holden type we measure the sag of an expanded wire. For a very small linear expansion the sag is comparatively great, hence a short wire may be used. In the figure two wires are used of same size and length side by side. In this way the external variations of temperature are compensated for. A cord attached to the live wire is held taut by a spring, and passes round a small pulley to move the pointer. This instrument is used as a voltmeter and as an

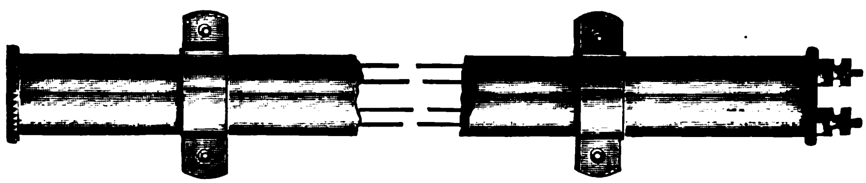


Fig. 84

ammeter of the shunted type, and is a valuable addition to our practical instruments.

Recently a horse-power meter has been brought out which indicates the horse-power of electrical energy supplied at the moment of inspection to a motor in the circuit. But such an instrument cannot be of much use, for the horse-power going in is of not much interest without knowing also the horse-power given out. A double instrument is far better, which indicates the pressure and current simultaneously; simple multiplication will then give the horse-power. In motors working on a constant pressure circuit

the important thing to know is the current; the variations in the current are the true indicators of what is going on in the motor. The variation in a horse-power or watt meter may be due to variations in voltage, current, or load in the motor. The variations in the current with constant voltage is due to load alone; hence it is of value to have an ammeter in circuit, a good dead-beat instrument with the smallest possible amount of inertia in its moving parts. The importance of these ammeter indications can be judged from a case in the author's experience. A 20 horse-power motor driving a pump in a mine, and constantly running, had its switchboard up in the dynamo room on the surface with a good dead-beat moving coil instrument. After a few days working the ammeter remained steady about 60 amperes. A red line at that point was fixed for the driver's inspection, thus showing the normal state of the motor and pump at a glance. The instruction to the driver was to go down to the motor immediately the ammeter deviated more than 5 amperes on either side, and as a matter of fact the ammeter indicated the time by a slight rise in current when it was necessary for the attendant to oil the machinery down below. In another case in a factory a motor driving three lines of shafting, which had never taken over 15 amperes, gradually increased to 20 amperes without any apparent reason; but an examination revealed the fact that one of the shafts had become badly out of line through the distortion of a wall. If there had been no ammeter in the circuit this would not have been discovered, and the waste would have gone on until something happened—the breakdown of the motor or the firing of the bearings on the faulty shafting.

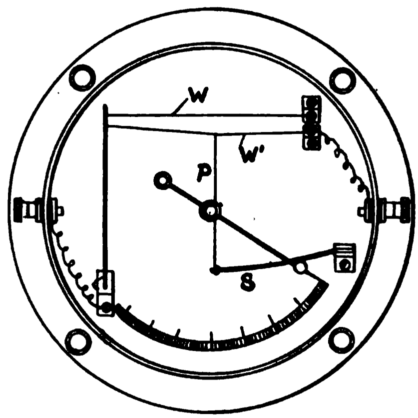
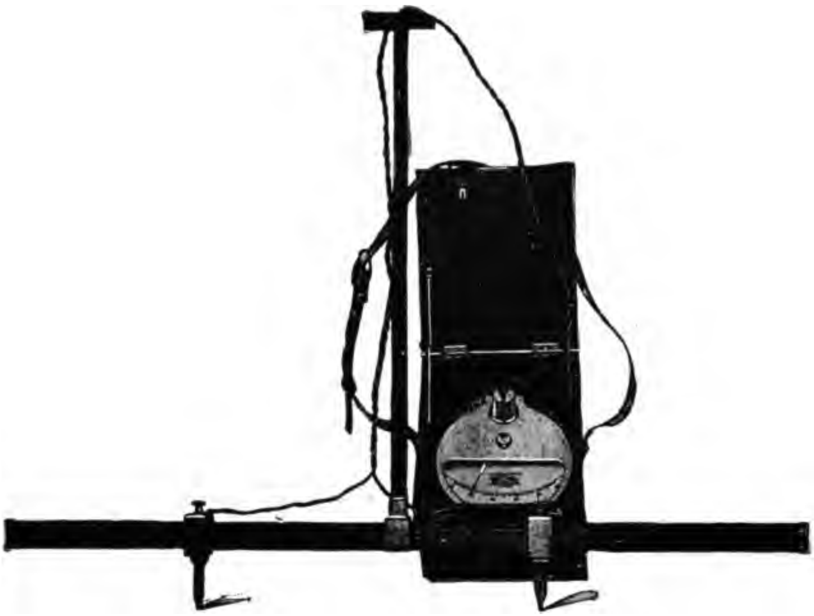


FIG. 85.—Holden Hot-Wire Voltmeter

Even on variable loads this indication is valuable, for the maximum variation under normal conditions can always be marked on the scale, and the attendant instructed to report all variations over that point. It is in this way that motors can be made efficient drivers by noticing the ammeter.

An instrument which every consulting engineer should have is one for testing conductivity, that is, in other words, the resistances of switches, fuses, instruments, and connectors on all installations. The Fire Office rules, and the municipal supply rules, make much of testing insulation resistance, as if that were the only factor of safety



Lord Kelvin's Rail-Bond Tester

Testing Rail-Bonds with Kelvin Instrument

or danger. Very few engineers trouble about conductivity tests; yet there is actually more danger in a failure of conductivity than in a failure in insulation, for a failure in insulation generally results in blowing out fuses, and is soon made manifest, but a failure in conductivity may result in a fire before the defect has been suspected to exist—no cut-outs or fuses can prevent it. Towards providing an instrument for conductivity tests, Lord Kelvin has brought out the instrument shown in the special Plate II. It is now applied, as shown, to test the conductivity of tramway rail-bonds; for making contact a graduated bar has two steel contacts attached to it, and various degrees of sensibility can be obtained by altering the position of the contacts on the graduated bar. By flexible wires the contacts are connected to a low-reading voltmeter, the deflections of which indicate the conductivity of the joint or bond.

An instrument on the same principles for testing installations, joints, connections, switches, fuse, and so on, is much needed for both alternating and continuous currents.

Another method of testing tramway rail-bonds has just been given in the *American Electrical Review* of New York. It consists of balancing the fall of potential across the rail-bond against the fall of potential on a length of the rail itself by a null method. Three contact poles are provided, one pair of which are held by the tester's assistant on either side of the rail joint, and the third is moved by the tester along the rail until balance is indicated by the cessation of a click in a telephone when making or breaking contact in the telephone circuit by means of a switch. No extra battery power is required, the ordinary current passing through the rail serving the purpose. The resistance of the joint is ascertained in terms of an equivalent length of rail.

In many instruments the acting forces and reacting forces are not compatible; in some instruments the electrical forces, or magnetic forces, acting as the square of the current or pressure; in others they act as the current or pressure directly, while the reacting forces may act directly as the force, such as a coiled spring or torsion wire, or as the sine of the angle of deflection, as in weight or gravity instruments.

The moving coil instrument, in which the coil moves in a uniform field and acts against a spring, is an example of an instrument in which the two forces are compatible, and we get an even scale.

The calibration of instruments is nowadays quickly and accurately carried out by comparisons made with standard instruments, such as Lord Kelvin's electrostatic voltmeters and standard ampere balances, these instruments being correct and unalterable. The balance is here illustrated (Fig. 86). All Kelvin balances are described in Vol. II.

For large switchboards instruments are made with scales edge-

wise so that a number can be ranged close together, as in Fig. 37. In some cases these have illuminated scales, lighted up by a small lamp inside; they are then easily read from a distance.

The Siemens dynamometer (Fig. 88) is an instrument of great use in

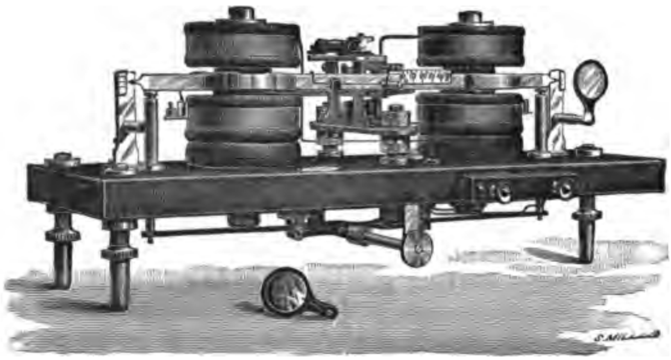


Fig. 86.—Kelvin's Standard Ampere Balance

the laboratory, having a long range and being equally correct on alternating and continuous current. It can be used as a watt-meter, in which case it has the fixed coil of very fine wire and the moving one of thick wire. The two coils (Fig. 89) are at right angles to each other at

Fig. 87.—Edgewise Instruments on Large Switchboard. By Evershed & Vignoles

zero, the force being measured by the torsion of a spring, as shown in illustration. It has a small amount of mutual induction between the coils, from which arises a slight error on alternating measurements of watts. In alternating measurements we have to consider the fact that the maximum electric pressure may not coincide with the maximum current; the pressure may reach its maximum value when the

current has only reached a small fraction of its maximum value. Hence, to read one on a voltmeter and the other on an ammeter would not give us the true watts, by multiplying the two readings together; but a watt-meter on the principle of the Siemens dyna-

FIG. 88.—Siemens' Dynamometer. Complete View

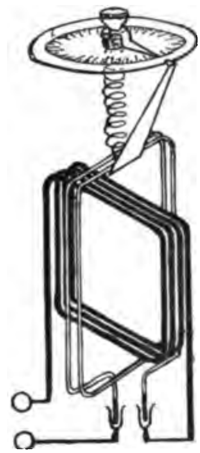


FIG. 89.—Diagram of Siemens' Dynamometer

mometer would give the true watts, however much the pressure is ahead of the current, for the torque of the instrument is proportional to the pressure multiplied by the current at any instant.

A method of using low-pressure voltmeters and dynamometers by reducing from high pressure in a known ratio by means of a transformer of alternating currents is shown in the diagrams below, Figs. 90, 91.

V is a low-pressure voltmeter, and W a dynamometer or watt-

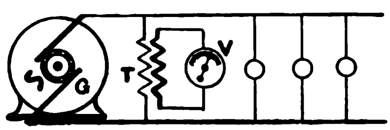


FIG. 90.

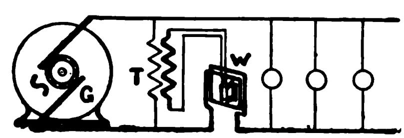


FIG. 91.

Rankin Kennedy's Pressure Reducer.

meter, and T is the transformer. This method was introduced by the author in 1886, and is now used for reducing the pressure on the fine-wire coils of supply meters, but for pressure measurements it is now superseded by electrostatic voltmeters.

CHAPTER IV

ELECTRO-MAGNETIC INDUCTION AND MAGNETS

THE electrical engineer has a great deal to do with magnets, for by means of magnetism and conductors, acted upon by magnetism and moved by power, he can pump up electrical pressure cheaper than it can be raised by any other known means.

Magnets are of two kinds—steel permanent magnets and soft steel or iron electro-magnets.

The making of good steel magnets depends both on material and workmanship.

Here is a table showing different values of residual magnetism found by different experimenters:—

TABLE VII.

Material.	Maximum Permanent Magnetism Lines per Square Centimetre.
Common tool steel	4000
Tungsten steel (tempered)	8000
Magnet steel (Jowitt's)	6500
Magnet steel (Walls')	5000

NOTE.—Results of different experimenters are very conflicting, principally due to different methods of testing and to tests made on different forms of magnets.

Tungsten steel seems best for the purpose. Magnets must be carefully forged, overheating and frequent heating avoided; if a magnet is to be bent it must be bent at a low heat, and at one, or at most two, heats.

The temper is of great importance. The best temper is not the same for all steels; but, generally speaking, the best temper is about that of clock springs.

The magnet must first be uniformly heated to a red heat, bright red, and quenched in cold water; a bright line should then be ground along its whole length; a large hot plate, uniformly heated, should then be used upon which to lay the magnets for the purpose of letting down the temper. The bright line will gradually change colour, first pale yellow, then deep yellow, orange, purple, dark blue, bright blue.

Immediately the purple tinge appears the magnet should be plunged into cold water; this fixes the temper.

This temper is good for most purposes; but small needles or bar magnets may be harder, orange or yellow.

With few exceptions magnets are used to produce a magnetic field in which something is to be controlled or actuated by the field of the magnet.

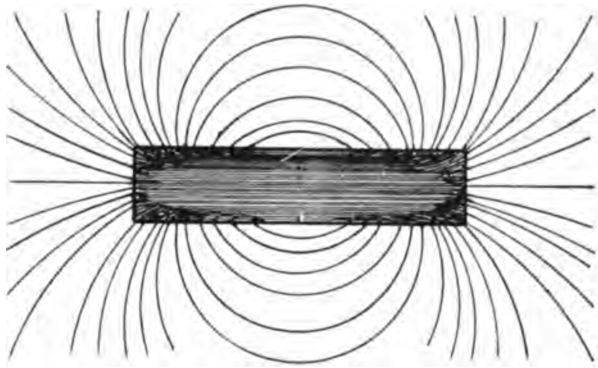


FIG. 92

We may therefore, for all practical purposes, study the field of horse-shoe or ring-shaped magnets, the field being more concentrated and more compact with these forms, and stronger for the same weight of metal.

Bar magnets are of no use except as compass needles or for the purpose of building up horse-shoe forms.

Fig. 92 is an illustration of a bar magnet, showing the lines of force in and running from it. The maximum force is at the middle inside the magnet; the force escapes sideways, so that at the ends there is not much magnetism issuing, or, to put it better, not many lines of force passing out, not nearly so many as pass through the mid section of the magnet.

This can be best ascertained by means of an exploring coil of very fine wire attached to a delicate galvanometer (Fig. 93). The

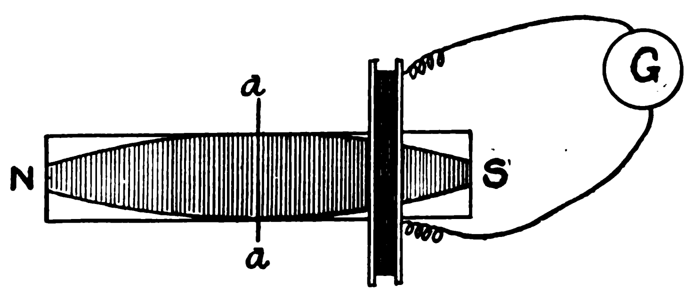


FIG. 93

coil fits easy over the magnet, and may be jerked forward about its own breadth step by step along the magnet. At every jerk the coil cuts across all the lines, escaping sideways from that point or section over which the coil moved, and the movement causes a current to flow in the coil and galvanometer which makes the needle swing to a more or less angle according to the number of lines cut.

By going step by step from end to end of a bar we can plot out the force from N to *a*. Suppose, beginning just outside the pole S, we find, say, 20 lines cut, then the next jerk gives, say, 18, next 15, next 10, next 5, next 2, next 0.5; this last near *a*, the mid section.

Then

$$\begin{array}{r} 20 \\ 18 \\ 15 \\ 10 \\ 5 \\ 2 \\ 0.5 \\ \hline 70.5 \end{array}$$

70.5 total lines through *a*.

So that as the end only gives out 20, and the total is 70.5, we see that although the end is the active part it does not carry the same number of lines of force as the middle.

This test is illustrated in Fig. 93, the shaded part showing the magnetic flux at each position. In the above example we might plot the shaded lines to a millimetre scale: the mid line *a* would be 70.5 millimetres, the line outside the pole S 20 millimetres.

The same thing can be done with any magnet. Mr. Albert Campbell gives a sketch of a ring magnet like Fig. 94, where the shaded part represents the flux at various points found by him by this method in a steel magnet as used in Weston instruments. Only one-third of the flux at *a* reaches the gap N S.

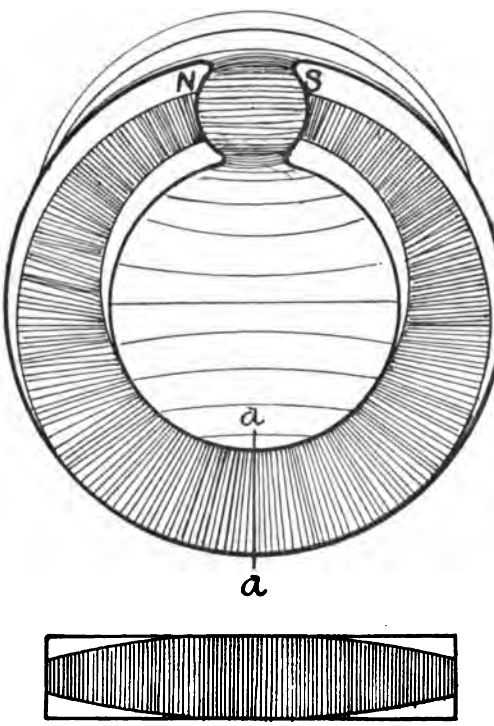


Fig. 94

Fig. 95 shows the lines of force due to a plain horse-shoe magnet. The leakage takes place nearly all across the space between the legs, and it can be measured, as shown in Fig. 96, by jerking the exploring coil along a bit at a time from pole to the bend, and so get the flux at all the different sections.

The lines leak out and take a short cut through the air and back round the bend.

But this leakage across is variable, for if we provide a good path for the lines at the poles, by putting on a large soft-iron keeper, and

FIG. 95

again jerking the explorer along, we will find hardly any leakage across the air from limb to limb, Fig. 97.

To show this more perfectly, let the exploring coil be placed right

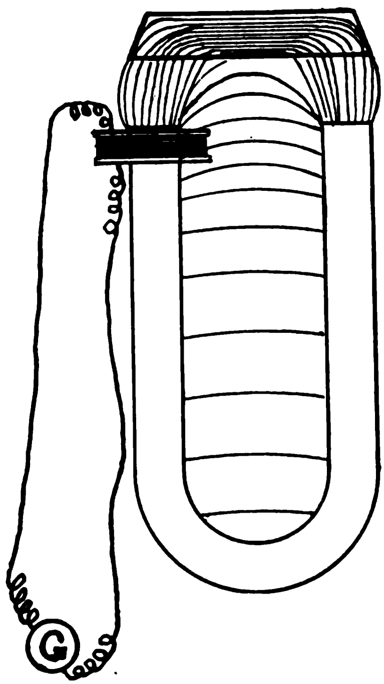


FIG. 96

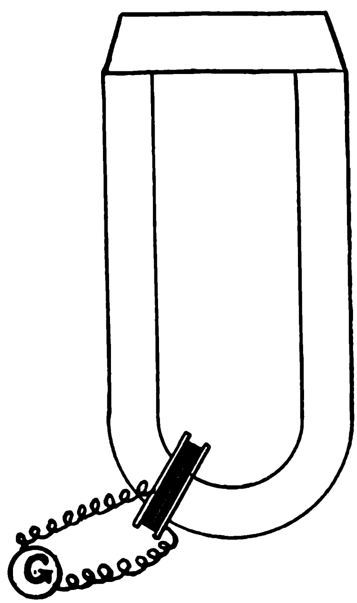


FIG. 97

on the bend; in this position pulling off and putting on the keeper has no effect; move it to position shown in illustration, and a slight effect is felt when the keeper is pulled off or put on. Moving it along

to various positions right up to the pole, it will be found that as we approach the pole the effect of pulling off or putting on the keeper is greater and greater.

The reason for the increased effect as we move towards the pole is that the difference in the flux through the coil is greater when the keeper is on than when off, and the difference is greater the nearer the coil is to the pole; at the bend it makes no difference whether the keeper is off or on. This experiment was first shown by Prof. S. P. Thomson in his Society of Arts Lectures on Magnetism. It proves that the magnetism is not increased by applying the keeper, but that it is concentrated through the keeper, instead of flowing through the air, when the keeper is on. The best form of steel magnet to produce a uniform magnetic field of greatest strength in a small field is that shown in Fig. 94.

The strength of this field is the all-important point for the engineer, yet it is about the only point regarding which the text books and scientific treatises are silent; pages of scientific tricks with magnets, filings, nails, and magnetic needles are given, of no value to any student, and when some day he wants a magnet for some practical purpose he finds no assistance given him as to how to proceed to specify its dimensions.

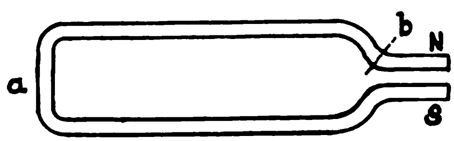


FIG. 98

In the case of magnet (Fig. 94), the steel at *a* was found to be magnetised to a density of 5000 per square centimetre; in the air gap it was 870 per square centimetre, that is, in the place where it is of any use.

30,000 per square inch is a good value for B in a steel magnet, that is, at the bend or mid section.

The total flux is never obtained at the poles, as we have seen. And it is exceedingly difficult to calculate the leakage in a horseshoe magnet; it depends on many things.

A ring shaped like Fig. 94, with no core of iron in the gap, will leak roughly estimated about two-thirds.

A magnet shaped like Fig. 98 will give half the total flux between the poles that there is at *a*.

Hence with a ring shape, if we require a flux of 60,000, we would require three times that amount in the mid line *a*, 180,000.

If the steel was good for 30,000 per square inch, then $\frac{180,000}{30,000}$ = 6 square inches section of steel required.

The number of lines flowing through the mid section of a steel magnet is the quantity which determines the strength of a magnet, and may be anything between nothing and 14,000 lines per square centimetre, according to the quality of steel, its temper, its form, and method of magnetisation.

The strength, therefore, depends on sectional area.

Length is required to give the magnetism stability. In a magnet we consider each molecule as a little magnet, that all these little magnets are turned end to end in a magnetised magnet, thus—

N——S N——S N——S N——S N——S N——S

So that the flux flows in series right through the lot. We can set up a lot of little needles on pivots to represent this theory. If we do so, we find that the longer the series the more stiffly do the needles keep in line.

If we have only two needles, and we arranged a large magnet

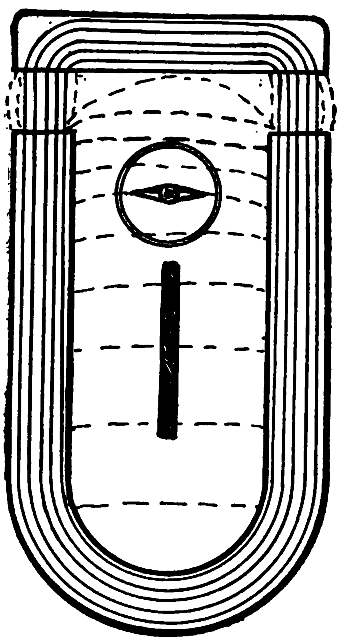


FIG. 99

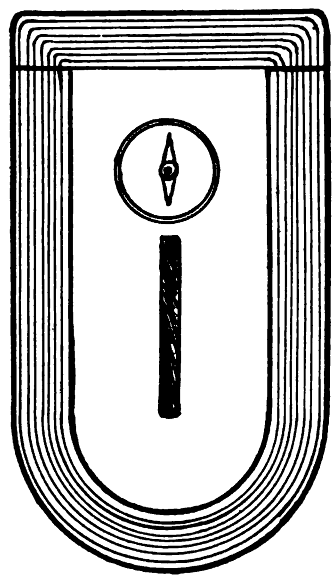


FIG. 100

to annul the earth's magnetism, leaving them free to act independently, they would set N——S N——S, as in a magnet, but a slight disturbance would alter the arrangement to this form, with no external field.

N S

S N

Leakage can also be shown by a small magnetic needle (Figs. 99 and 100). When the keeper is on, as in Fig. 100, the flux is almost all through the keeper, and a small controlling magnet can keep the needle parallel; but upon removing the keeper, the force

of the magnet spreads across and the needle is turned at right angles by the strong field.

Figs. 96 and 97 may be referred to as showing two methods of inducing electric currents by magnets, first by moving the coil on the limb of the magnet, thereby cutting across the magnetic lines of force; and secondly, by fixing the coil, and pulling off or putting on the keeper. In this last case the lines move and cut the coil when the keeper is moved.

Figs. 101 and 102 show the usual construction of permanent magnet fields. It will be noted that the pole-pieces and armature

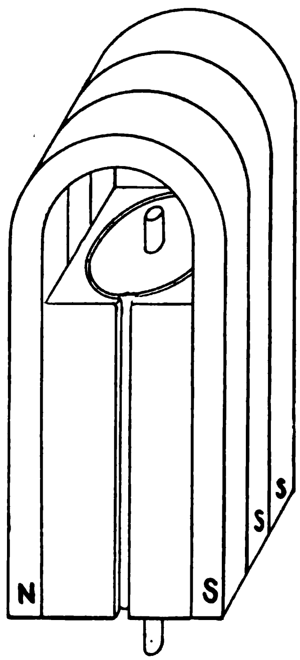


FIG. 101

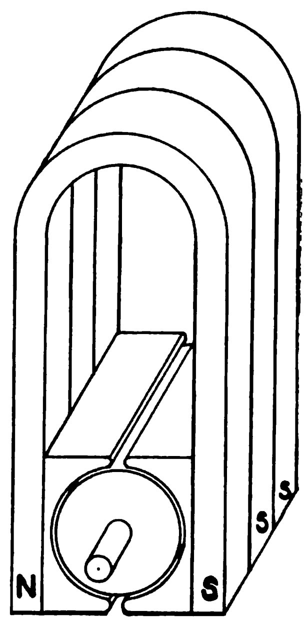


FIG. 102

form the keeper and close the magnetic circuit, so that the magnetic flux is concentrated upon the armature.

These magnets should be magnetised with the pole-pieces and armature in their places. In this way the magnetisation is more perfect, as the path of the lines of force shall then be arranged as they are intended to be used.

If we look upon magnets as made of a series of end-to-end small magnets, then we can see that a long series is more stable than a short one; for although the total magnetic flux is not increased by added length, the directive force is increased—that is, the force which keeps them in line—and the magneto-motive force is increased in proportion to the length of the line of magnets.

The effect of length may be seen by taking, say, six bar

magnets, and placing them end to end, N S, N S, N S. By doing so, we increase the force to six times that of one, but we also increase the internal resistance and the external resistance by six times; so that we have no more flux with six than with one. But we have six times the force directing the molecules in the magnetic circuit.

The proper length cannot well be calculated, but it has been found by experiment that the proportions shown in Fig. 103 gave the best results; the sectional area is one-twentieth the length of the steel in this magnet. Twenty times the sectional area is a good practical rule for horse-shoe and circular shapes.

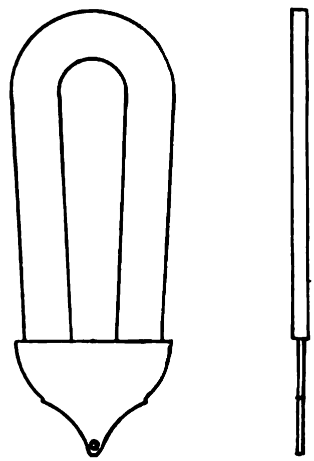


FIG. 103

The magnetisation of magnets is of importance. The only perfect method is to magnetise them by a current of electricity in a coil of wire. The horse-shoe should have both limbs thrust into a coil of wire of the largest size possible, and a current of a density of at least 4000 amperes per square inch section of wire sent through the coil with the keeper on the magnet. The current may momentarily be increased to 6000 density in the coil. The aim in magnetising is to get the greatest number of ampere-turns possible round the magnet.

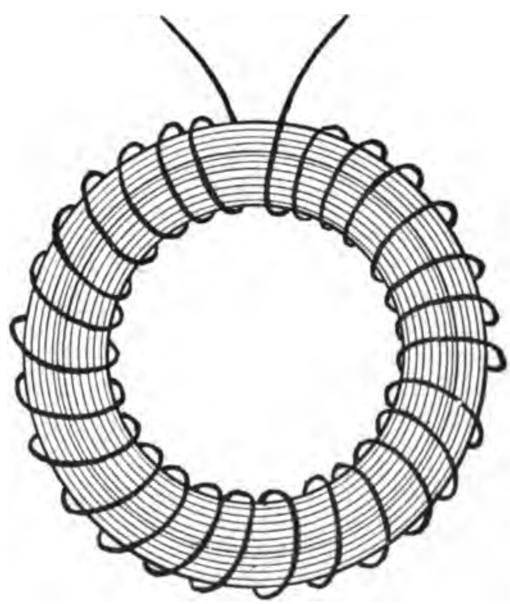


FIG. 104

If the magnetising force is weak the magnetism remaining after the force is removed is found to be only skin deep.

Thick magnets are difficult to forge, to temper, and to magnetise uniformly, hence they are never so strong as flat thin magnets in proportion to their weight; for this reason, it is better in making large magnets to build them up of a number of thin magnets. Four horse-shoe magnets a quarter of an inch thick, one

inch broad, built up to form a magnet one inch square, and each separately magnetised, are together much stronger than one made of a bar one inch square solid.

Good steel magnets have a lifting or tractive force of about twenty times their weight when made horse-shoe shape and fitted with a keeper slightly narrower than the poles.

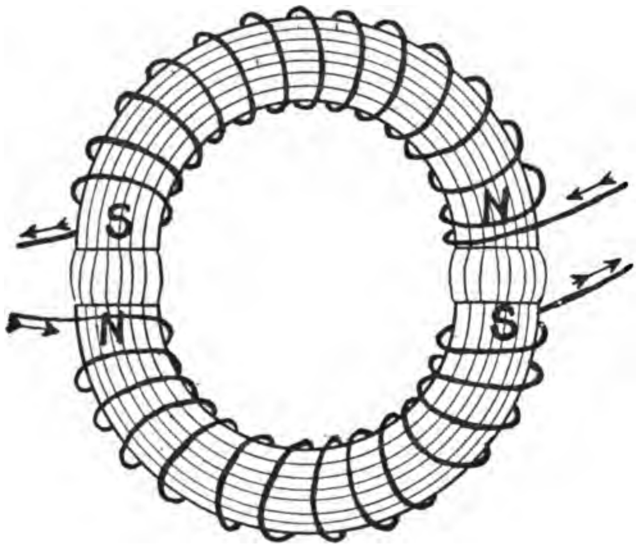


Fig. 105

Magnets of steel are used in meters, voltmeters, ammeters, telegraphs, and telephones, and in magneto-generators for ringing bells and signalling. And they have been used in large generators for generating current for lighthouse purposes by De Meritaus.

The earth is a permanent magnet; hence, in cases where magnets are free to move or wherein a magnetic field can be influenced by it, that magnetism may be taken into account. It is the controlling field in the tangent and many other galvanometers, also in the mariners' compass.

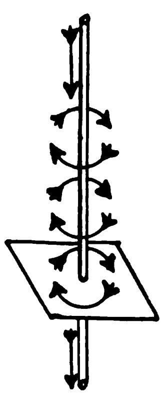


Fig. 106

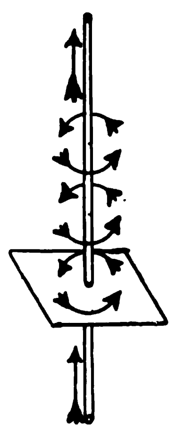


Fig. 107

If we have a complete magnetic circuit, say a ring of iron or steel, there is no external leakage. The number of lines of force are the same all round, as in Fig. 104.

If an insulated wire is wound upon such a ring and electric current passed through the coils the ring will be strongly magnetised without poles. If we wind a second coil over the first and make and break the electric current of the first coil, we shall get induced current in the second coil, due to the magnetic flux in the iron ring. This was first shown by Faraday.

If, as in Fig. 105, the ring is cut and magnetised by one coil, poles shall be found as shown, and electric current shall be induced in the

second coil by pulling the two halfs apart. In all electro-magnets we have a current-carrying coil or coils of wire and an iron core to be magnetised, in which there are, in most cases, gaps, across which the lines of magnetic force pass from pole to pole, as in Fig. 105. A wire carrying a current is surrounded by a magnetic field, as shown in Figs. 106 and 107, and when coiled up a field of magnetism surrounds the coil, as in Fig. 108.

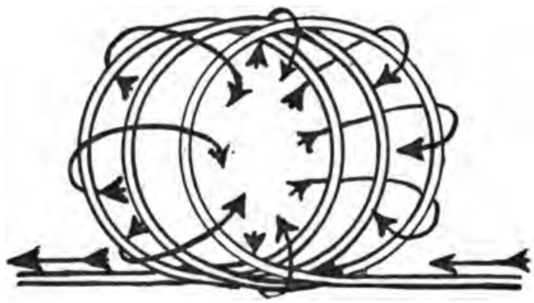


FIG. 108

The magnetising power of a coil depends on the ampere-turns in it, the current multiplied by the number of turns. If we wind up a bobbin of insulated wire, as in Fig. 108, and send a current of ten amperes through it, its magnetising effect is equal to 1000 ampere-turns if the number of turns is 100.

Such a coil is called a solenoid, and behaves, when current flows in it, exactly like a magnet.

And when solenoids are fitted with iron cores they become electro-magnets, and in making electro-motors and dynamo electric generators, solenoids and iron cores have to be calculated out according to requirements.

In Fig. 104 we have a solenoid on an iron ring. If the solenoid were empty or on a wooden ring the number of lines of magnetism carried through it would be small compared with the number when the ring is of iron, for iron is a much better conductor of magnetism. Hence, in a closed magnetic circuit, that is, one all of iron, we get the greatest effect of the current in the solenoid.

If we break the circuit, as in Fig. 105, the two gaps offer great resistance to the lines flowing, and the amount of flow will be reduced all round the circuit. In all magnetic apparatus we have this magnetic circuit through which the magnetism is conducted.

Fig. 109 shows an elementary magnetic circuit. It may be a steel magnet, but we shall consider it an electro-magnet with one turn of wire. The lines of force will circulate through the horseshoe of iron across two air gaps, and through the cylindrical armature, also of iron.

Neglecting leakage, it is evident the amount of flux all round is the same in quantity, so that the sectional area of the iron magnet should be equal throughout. It would be bad design to make the yoke less in section than the limbs.

In all good designs for magnetic circuits, the path of the mag-

netic flux is made equal in conductivity as nearly as possible in the iron parts of the circuits.

A magnet might, for instance, have a cast-iron yoke and wrought-iron limbs; but as the cast-iron has only half the conductivity of the soft wrought-iron, it would require to be twice the section to carry the same flux as the limbs.

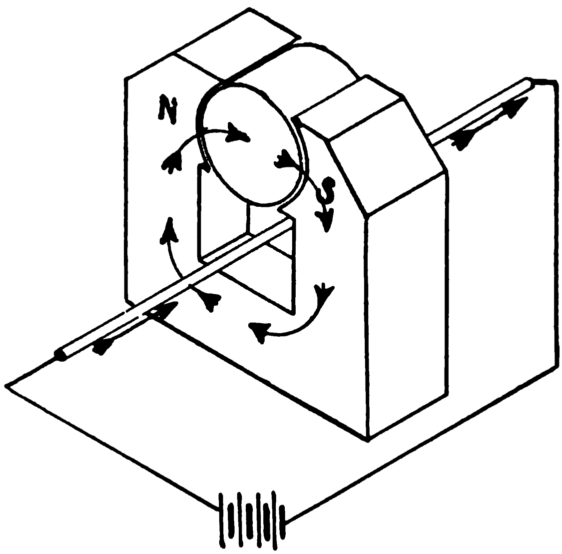


FIG. 109

Another important point is that the iron in an electro-magnet does not become magnetised in proportion to the ampere-turns passing in its solenoids; it becomes saturated.

If we take a large solenoid and a soft-iron core and begin with a current of 1 ampere, a certain magnetic flux will be found; and if we now send 2 amperes through we may get double the flux; with 4 amperes, less than four times the flux with 1 ampere; with 8 amperes, not much more than we got with 6 amperes; and we might find that after we reached 8 amperes the magnetism was not increased by any increase of current beyond 8 amperes.

Practically the flux becomes constant. To enable calculations to be made, the flux is represented as so many lines of force per square inch or per square centimetre of the surface from which it proceeds.

In engineering work in this country we still adhere to the inch, foot, yard, pound, cwt., and ton units, so that conversion calculations are required to reduce these to C.G.S. units, and even in using the C.G.S. units themselves the numbers are very large and laborious to calculate out by ordinary arithmetic. Referring back to what has been said about steel magnets, we had to use numbers like 30,000, 180,000, for quite small magnets, while in dynamo magnets we would require to deal with millions and millions, the fact being that the line of force is far too small a unit for practical work.

The line of magnetic force is just one-millionth of what it should be.

For dynamo and motor calculations by ordinary arithmetic a

system of units based on the inch-lb. system has been in use. It was first proposed and used by Mr. Gisbert Kapp.

B is usually employed as a symbol for the density of the magnetic lines per square inch in English measure.

$\mathfrak{B}$ the density per square centimetre in C.G.S. system.

Thus a flux of $\mathfrak{B} = 15{,}000$ per square centimetre would be equal to $\frac{15{,}000}{930.04}$ per square inch English measure—that is, 16 nearly: 16 being a number much easier handled than 15,000.

Kapp has calculated out tables of the values of B for different numbers of ampere-turns, from which the following Table VIII. has been drawn.

The English lines of force are found as above by dividing the C.G.S. lines by 930.04, thus giving small numbers for calculations.

$$B = \frac{\text{C.G.S.}}{930.04} \qquad \mathfrak{B} = B \times 930.04.$$

Table VIII.

Ampere-turns required per inch length of wrought iron or soft steel for different values of B :—

B.	Ampere-turns per inch length.	B.	Ampere-turns per inch length.
5.0	4.85	13.6	20.6
10.0	9.7	13.8	22.0
11.0	11.3	14.0	23.5
11.5	12.3	14.2	25.5
12.0	13.43	14.4	27.7
12.5	15.2	14.6	30.3
13.0	17.2	14.8	33.2
13.2	18.2	15.0	37.3
13.4	19.4		

Table IX.

Ampere-turns required per inch length of cast iron for different values of B :—

B.	Ampere-turns per inch length.	B.	Ampere-turns per inch length.
5.0	19.4	6.2	30.7
5.2	20.6	6.4	34.0
5.4	22.3	6.6	37.2
5.6	24.1	6.8	42.5
5.8	26.0	7.0	48.5
6.0	28.3		

These tables have been made out from actual tests.

In Table VIII. it will be noted that while when $B=5$ the ampere-turns required are 4.85; when $B=10$, ampere-turns equal 9.7, just proportional; but when $B=15$, the ampere-turns equal 37, so that by increasing ampere-turns from 9.7 to 37.3 we have only increased B from 10 to 15.

And to increase B from 14 to 15, that is, by only one line, we require an additional 14 ampere-turns added to the 23 required for $B = 14$.

It will be seen from these figures that after a wrought-iron magnet reaches a magnetisation of 14 per square inch, it would cost a great deal for copper and current to raise it to 15.

And a glance at the table for cast iron shows that when $B=7$ it is about saturated, and to raise it higher would require an exorbitant amount of winding.

To apply these figures in practice is interesting.

The easiest example is that of the iron ring (Fig. 104). We will suppose it has a mean length of 20 inches, made of a soft-iron bar of that length, and we wish to magnetise it up to 12 lines per square inch of its section, what amount of wire must be in the solenoid?

First find the number of turns of wire required.

At 12 lines 13.43 turns per inch are required at 1 ampere, or 1.343 turns if we use 10 amperes. We will assume 10 amperes, then, $1.343 \times 20 = 26.860$, say 27 turns in all.

Now turn back to Table VI. of covered wires and select a wire. As there are few turns, it may be thinner than if a great many layers were required, say No. 14, S.W.G.

Suppose the bar of iron to be $2 \times 2\frac{1}{2}$ inches, it will evidently take 9 inches fully to go round it, and $9 \times 27 = 243$ inches, or 20 feet 3 inches of wire. The weight of the wire and its resistance can all be found by easy calculation from the data given in Table VI.

B is equal to the lines per inch sectional area, so that the student must note that $B \times A$, the area of the section, will give the total flux. A is equal to $2\frac{1}{2} \times 2 = 5$ square inches; hence, $12 \times 5 = 60$ will be total number of lines formed in the ring.

Now take the case of Fig. 105, with two air gaps. If we require still to have a flux of 12 lines per square inch section, we will require to add ampere-turns to magnetise the air gaps.

Suppose the bar same as before, the gaps, say, 0.75 inches each, the two together 1.5 inches. Now air takes about 1880 ampere-turns per inch length, so that we require $1.5 \times 1880 = 2820$ per line of force, and as we require 12 lines, the total ampere-turns for the two gaps will be—

$$2820 \times 12 = 33{,}840 \text{ ampere-turns};$$

so that we see that while 270 ampere-turns suffices to magnetise the iron, it takes 33,800 to magnetise the air gaps to the same degree per square inch section.

In the same way coils for magnetising the horse-shoe magnets, Figs. 99 and 100, can be calculated, both with armature off and on.

The magnetising power in ampere-turns can be reduced in an air gap by pole-pieces, as shown in Fig. 110. These are added to the polar ends, so that the area of the air gaps can be increased; the resistance is thereby decreased.

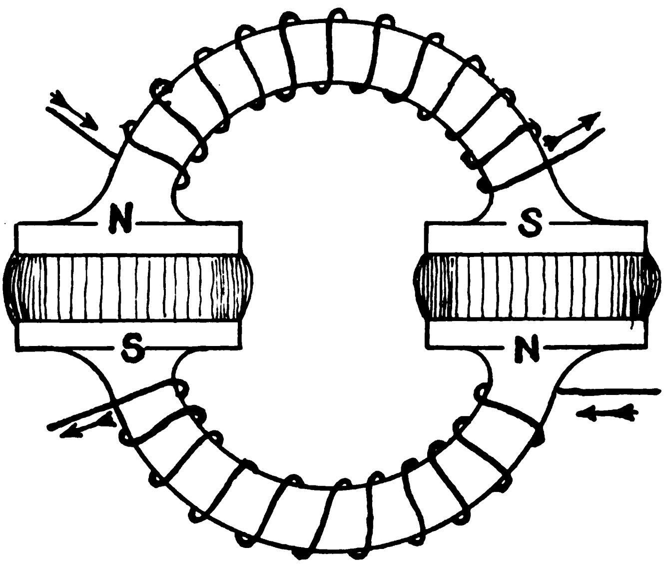


FIG. 110

We have to multiply the length of the air gap by 1880, and by the density per square inch. If we double the area across which the lines flow in air, we halve the density, and so in proportion get half the resistance.

The density in the air gap is equal to the total number of lines divided by the area. The total we found before was 60, so that if, by spreading out the poles as shown in Fig. 103A, we made the area 4×5, or 20 square inches, $\frac{60}{20} = 3$ lines per square inch density in the air gap, and 1.5 for their combined lengths.

The ampere-turns required would now be—

$$1.5 \times 1880 \times 3 = 8460 \text{ instead of } 33,840.$$

This explains the use of pole-pieces on magnets. They are merely of service in reducing air-space resistance to magnetisation.

We get the same total flux as before with one-fourth of the ampere-turns by expanding the poles.

Such a device for the purpose of saving ampere-turns is not always beneficial.

It certainly is not in dynamos and motors, for the field is weakened per square inch, and the magnetic metal of the extended poles form magnetic circuits of their own with the armature and its winding. In modern practice large pole-pieces are not used, the air gaps having a little more than the sectional area of the magnets, the density of the magnet flux being nearly the same in both.

Field Magnets

Fig. 111 is a diagram of a single bobbin single horse-shoe magnet.

Fig. 112 is a diagram of a double bobbin single horse-shoe magnet, called undertype in this position, and overtype when upside down.

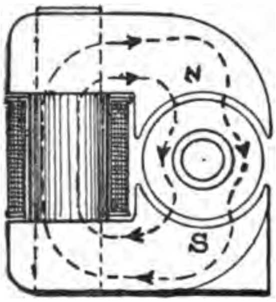


Fig. 111

Fig. 113 is a double bobbin double horse-shoe magnet, and Fig. 114 a diagram of another of same kind.

Fig. 115 is a multipolar magnet diagram. In all these the path of the lines of force is shown by dotted lines. And to calculate the total flux, we may take as an example the Fig. 112.

The two limbs are of soft steel, 9 inches square, giving 81 square inches section, the yoke having the same section, and being 6 inches long.

The armature is 14 inches diameter and 9 inches long, and has a sectional area of iron about equal to the magnets. The length of the field bobbin is 10 inches. The mean length of the path of the magnetic lines is approximately 50 inches.

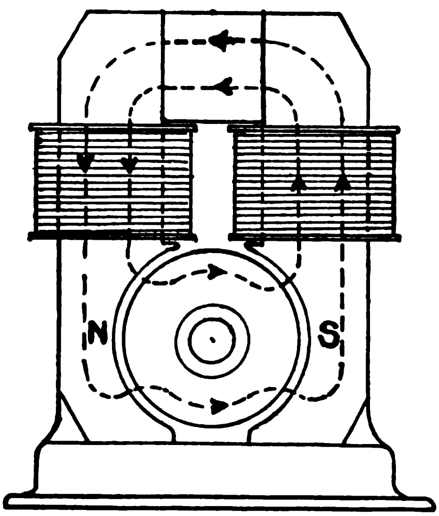


Fig. 112

From these dimensions, easily obtained by a foot-rule, we can calculate out the magnetic data of this magnet. We will take the iron first, the air gaps afterwards.

To make the best use of the magnets we must run up the density of the lines to 14 lines per square inch at least. According to our Table VIII. we get 13.8 lines per square inch, with 22 ampere-turns per inch of magnetic circuit length, and as all the parts are of soft steel, we may take them all in as one length—50 inches; so that, $50 \times 22 = 1100$ as ampere-turns for the iron circuit. To this should be added for joints 5 per cent., as there is always some resistance there, making 1150 ampere-turns.

The total flux will be equal to the sectional area, multiplied by the flux per square inch—$13.8 \times 81 = 1117.8$. Of this amount about 10 per cent. must be deducted for leakage; sometimes it is as much as 20 per cent. for lines which get across from limb to limb without going through the armature.

Now, for the air spaces, we will take them at $\frac{1}{8}$th inch each, $1\frac{1}{4}$

inch for the two, making the bore 15¼ inches. There is six inch spaces between the inner faces of the limbs, so that if we take 12 inches from the circumference of the armature tunnel, 48 inches, we will get the length of arc of the polar circle forming the N and S pole faces; this will give 18 inches, and as the length of the armature tunnel is 9 inches, the area is $18 \times 9 = 162$, just double the section of the iron.

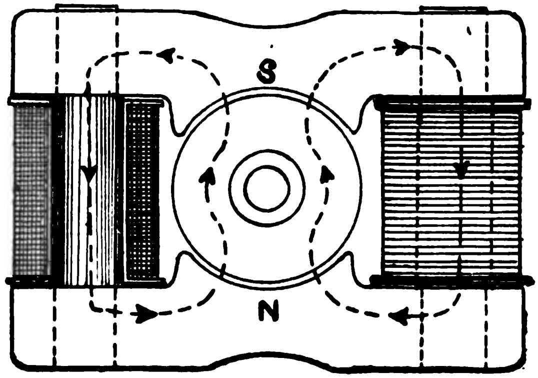


FIG. 113

If now we divide the total flux by the air space area, we get the flux there per square inch, $\frac{1000}{162}$; we get 6.2 approximately.

We can now find the ampere-turns to send this flux through the air gaps.

$L \times 1880 \times B = 1.25 \times 1880 \times 6.2 = 14{,}570$ ampere-turns; add to this the 1150 for the iron, and we get a total of 15,720 as total ampere-turns.

Roughly estimated, the exciting current for such a machine working at 250 volts pressure would be 2 amperes, so that the total turns of wire would be $\frac{15{,}720}{2} = 7860$, and $\frac{7860}{2} = 3920$ on each bobbin.

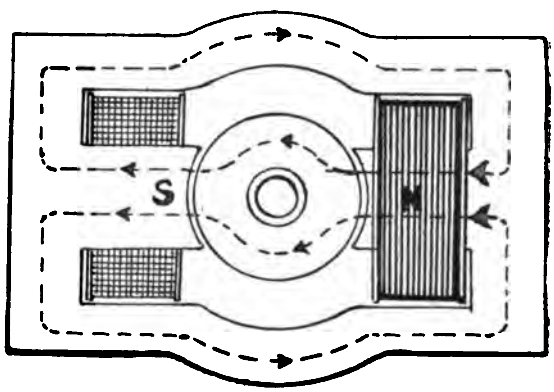


FIG. 114

By Ohm's law the resistance of the wire would be $\frac{E}{C} = R = \frac{250}{2} = 125$ ohms.

And we have now to find from the wire tables a wire which will give 125 ohms resistance; or 62.5 ohms and 3920 turns on each bobbin.

Several wires may be tried by calculation, taking the biggest section which will fit into the space allowed—try No. 17 S.W.G., cotton covered. We will allow 2 inches for maximum depth of winding, so that the mean length of one turn is equal to 44 inches.

We may take the number of turns required on one bobbin as equal to 4000, to avoid fractions. 4000×44 inches $= 4888$ yards of wire. Looking along the table we find this wire has 9.7 ohms per 1000 yards; therefore 4888 yards $\times\ 97 = 47$ ohms, while we require 62.5; but this means only a slightly higher exciting current, which can be regulated by a resistance in the coil circuit. And the total weight of the wire can also be calculated from the table of wires. We have now carried through the calculation of magnets with a simple circuit; if cast iron entered into the construction, say for a yoke or a pole-piece, then the calculation would be made for those parts separately, and the density reduced to about 7 per square inch for cast iron. For the multipolar design the calculations are the same. It is simplest to take two poles only to find the winding required for a multipolar machine, and multiply by number of poles afterwards. A good example of a multipolar design is shown in Plate III.

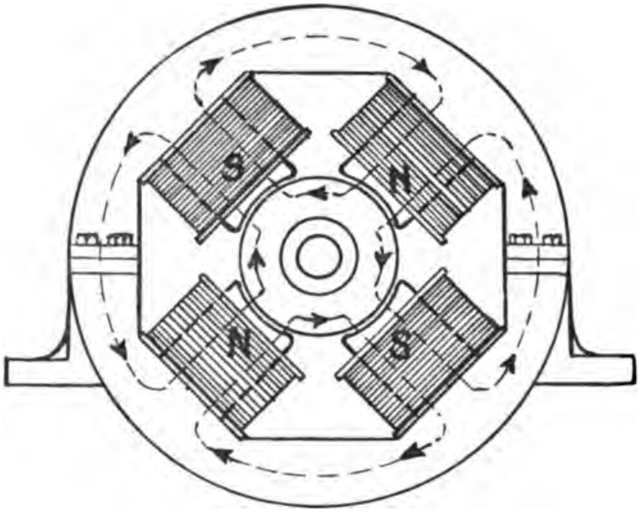


Fig. 115

In most multipolar magnets the magnet limbs are now made of laminated soft steel, and the yokes of cast steel or cast iron.

Dynamo magnets are now rarely made of wrought iron or steel forgings. The perfection of the processes for making castings of mild steel has enabled the engineer to use castings, which are preferable; for while quite as good as forgings, and no more expensive, they can be moulded into more economical and better designed forms, and, generally speaking, do not require the same expenditure of labour in fitting them for the machine; and some steels give even better results than those shown in Table VIII., and work up to as high as 18 lines per square inch, without using an extraordinary amount of winding. Especially in large dynamos is it important to select the very best material for magnets.

It will be gathered from the foregoing figures that magnetic circuits are very like electric circuits, inasmuch as:—

1. The resistance to the flux is directly proportional to the length of the circuit.

Typical Field Magnet Multipolar for Continuous Current. Crocker-Wheeler Design

2. Resistance is inversely as the cross sectional area.

3. Resistance depends on the kind of material. Instead of electric pressure or P.D. in volts we have magnetic pressure in ampere-turns, for which let M stand, and R for magnetic resistance, F for flux, then $\frac{M}{R} = F$.

The great difference between the two circuits is, that while we can confine the electric flux to the conductor by dielectrics or insulators, we cannot confine the magnetic flux: there is no insulator for magnetism. A magnet will send its force across air, wood, brass, and all bodies, in quantities depending on the form of the magnet and its poles.

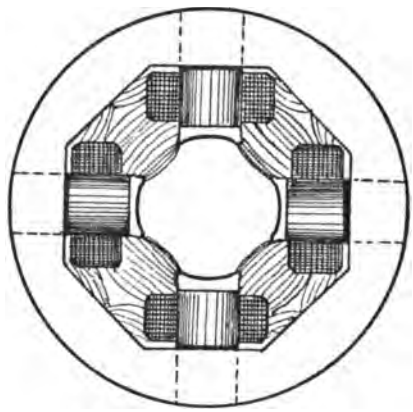


FIG. 116

The only way to confine the flux to a required path is that shown by the ring magnet, wherein the ring is such a good conductor compared with the air that there is not sufficient magnetic pressure difference between any two points to cause a side leakage. Hence, in all designs for magnets the circuit is made as much as possible like a ring—that is, with a closed magnetic circuit.

An examination of the magnets herein referred to shows that they are closed circuits—all but the necessary gap between the field-magnet and armature, to allow of free rotation. In this way leakage has, in modern magnets, been reduced to a very small value. In first-class machines it is not more than 10 per cent.; that is, of 100 lines produced by the field windings, 90 pass through the armature, where they are useful. Fig. 116 shows a multipolar field with lines to denote the leakage from pole to pole. It is to be noted that the stray force is all inside the enclosing yoke, and this is ensured in best designs by making the yoke a broad thin band, well covering over the coils. Magnets of this type have no external fields apt to damage watches. Whatever stray magnetic lines there may be, they are inside the yoke, which forms a magnetic case to the machine. Fig. 117 is the common bipolar horse-shoe field-magnet, showing by lines the leakage or stray field. It is strongest between the limbs, but there is also a considerable stray field (top, bottom, and sides), which can easily be found by the effect on spanners or keys brought within a short distance, and often by its effect in magnetising and stopping watches.

In most dynamos and motors a considerable fringe of magnetic force appears at one edge of the poles, as shown in Fig. 118 at *a*, spreading from the pole to the armature (only a portion of each being shown). The fringe appears at the corner to which the armature is moving, as shown by the black arrow in a dynamo; but in a motor it appears at the opposite corner, as shown by the dotted arrow. This fringe has the effect of shifting the pole surface apparently round the centre, for the lines stretch round out from the pole at the one corner, and are driven in by the armature at the other corner, that is, when the machine is working with current. This effect must be fully examined later on.

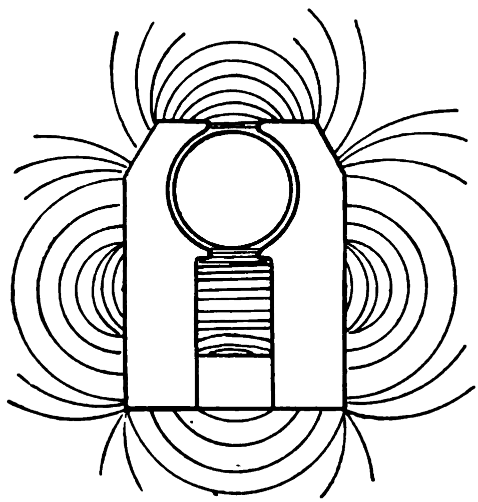


FIG. 117

The different methods of dynamo field-winding are shown in diagram in Figs. 119, 120, 121. The first one (Fig. 119) is a series field-winding—that is, the armature, the field coil, and the working circuit are all in series receiving the same current. This winding is used in motors on tramways, as it is cheaper and lends itself to control more readily than the other two. At one time there was an idea prevalent that a series motor had a greater starting-power than a shunt motor—an idea obtained in the early days of dynamos when they were built without any regard to the magnetic circuit, with weak fields and strong armatures, armatures with large internal resistance and many turns of wire; but we now know that the field-magnet can reach a strength beyond which no additional current can make it any stronger. That being so, the great starting-power is due simply to the great current in the armature, and that can be made equally great however a machine is excited. If it is excited up to 16 or 17 lines per square inch section, the field is practically constant.

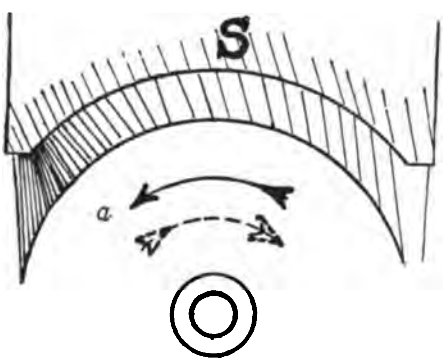


FIG. 118

The series winding is also useful for running arc lamps in series. For this purpose the field-magnet must be worked at the highest

possible flux density, and the armature should be large and, as a magnet, very powerful, so that when the normal current is exceeded the field is actually weakened by the flux from the armature poles. If the field is not over-excited and the armature flux weak, any decrease of resistance in the circuit would result in an increase of current, whereas we want a constant current in a series circuit.

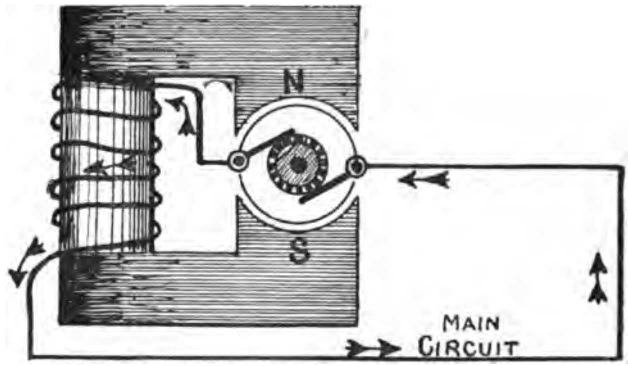


FIG. 119.—Series Wound Dynamo

The old B Gramme, the Pilsen Schuckert, the Brush, and Elihu Thomson arc lighting machines, now obsolete almost, were built with powerful armatures which automatically regulated the current by their reactions.

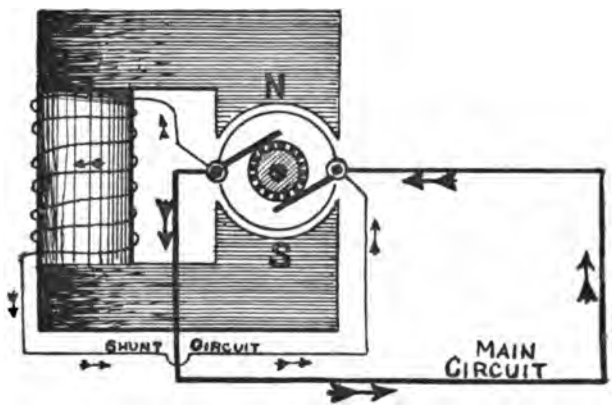


FIG. 120.—Shunt Wound Dynamo

The shunt dynamo (Fig. 120) has a fine wire field bobbin of sufficient resistance and length of wire to give the proper number of ampere-turns to fully excite the magnet, and is connected right across the brushes or poles to get the full pressure. Usually a variable resistance is included in order to regulate the pressure. If we break the circuit of a series machine the magnetism ceases, but we may vary the current in the external circuit of a shunt machine without affecting the field. A shunt dynamo should have the field very powerful and the armature weak, as magnets. It is better to get up the pressure by a strong field than to increase the armature turns.

The dynamo (Fig. 121) is wound with both a shunt and series coil; is, therefore, called a compound dynamo. In these machines the shunt coil is calculated to give the full pressure at no load and with the magnet not fully excited, so that when the current increases in the external circuit it passes round the series coils and increases the

magnetism, and so raises the pressure to compensate for the drop in pressure due to the resistances in the armature circuit. By this means a dynamo is made self-regulating, and can be made, in fact, to compensate for the fall in the speed of engine as the load goes up; and, further, can be made to give a higher pressure at full load than at no load.

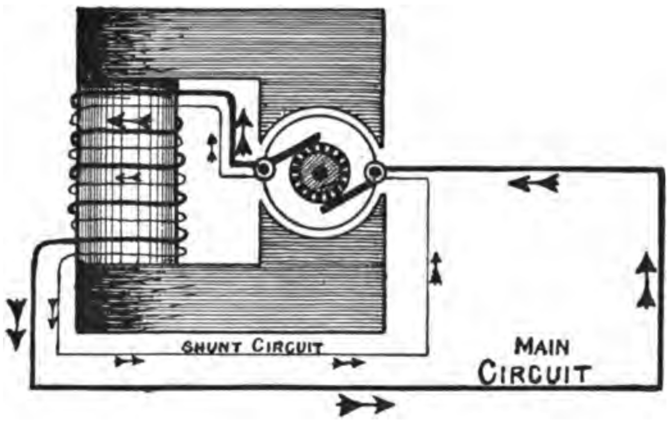
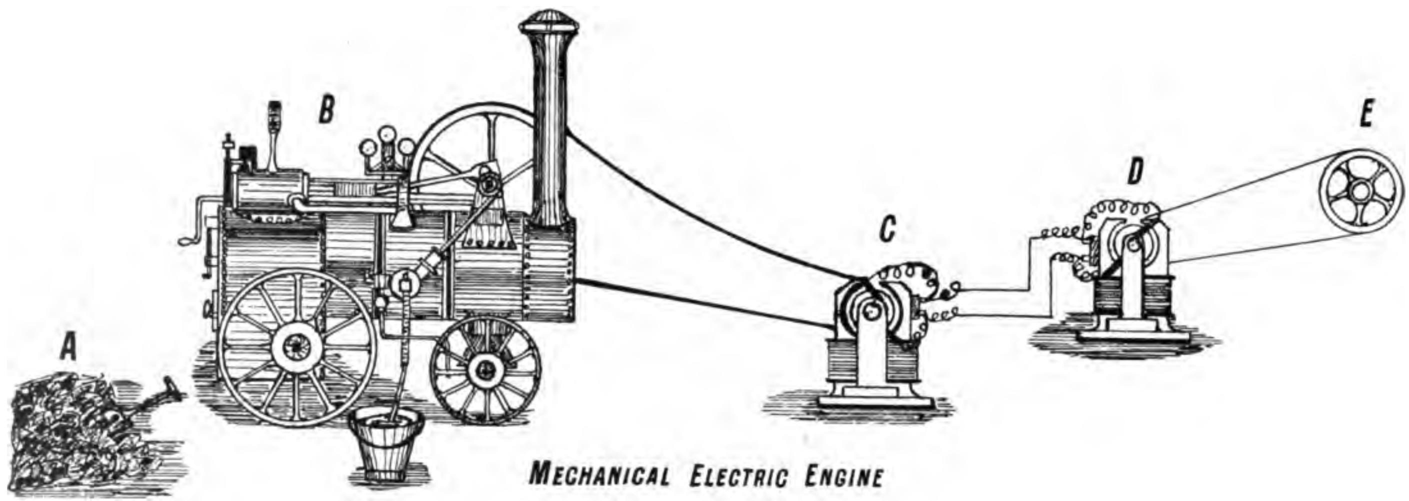


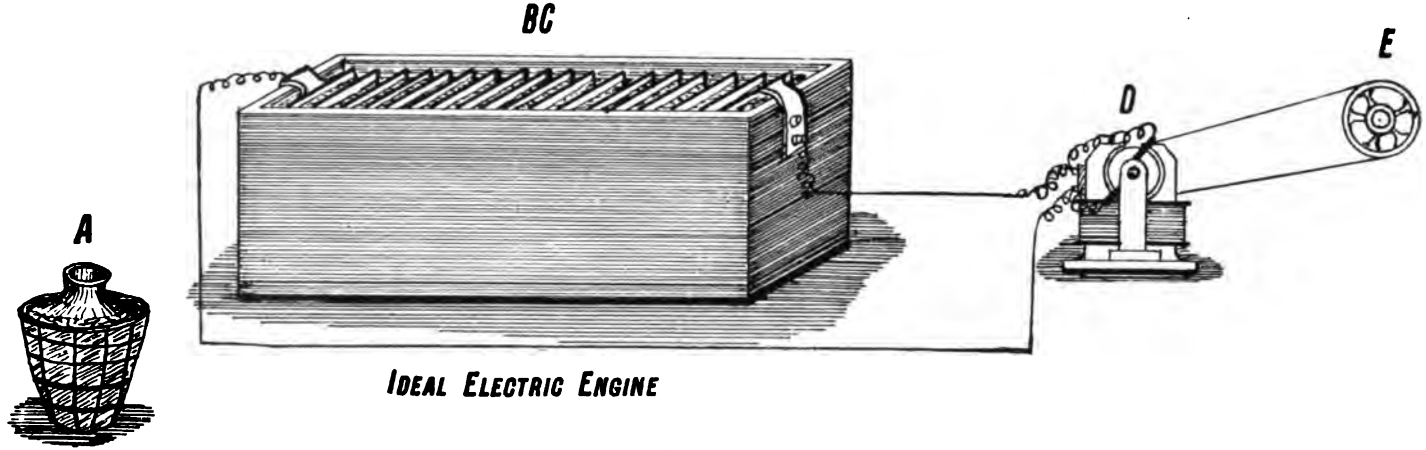
FIG. 121.—Series-Shunt or Compound Wound Dynamo

For series motors the field should be powerful and armature weak comparatively, and the same for shunt motors. A series motor on a constant pressure circuit will run up to an enormous speed if only lightly loaded, and will fall in speed as load goes on. They are not self-regulating, hence can only be used on cars or boats, or hitched to something which they cannot run away with. A shunt motor runs at practically a constant speed whatever the load. It should not vary 5 per cent., and if absolute constant speed is required we use a compound motor in which the series winding opposes the shunt winding and weakens the field as the load goes up; for if we weaken the field of a motor it runs quicker, because of the counter pressure generated in the armature becoming less. A motor, when running, acts as a dynamo generating a counter pressure opposed to the working pressure, and the armature runs up to a speed sufficient to balance this counter pressure. At no load the difference between the counter pressure of the motor and the pressure feeding it is very small, just sufficient to pass enough current to run the unloaded motor; but as load goes on the speed falls, and the difference in pressure becomes just great enough to pass the proper current strength. Thus the motor, reacting as a generator, is self-regulating, and takes just sufficient current to overcome the load on it at any moment. If we weaken the field the speed must go up to raise this counter pressure.

Variable speed motors should be shunt wound, and the speed varied as far as possible by a resistance in the shunt circuit. With all the resistance in, full speed will be got, and with all out lowest speed. This is as it should be, for at low speed we want most torque, and at high speed less torque, to get same power in both cases.



MECHANICAL ELECTRIC ENGINE



IDEAL ELECTRIC ENGINE

CHAPTER V

ELECTRIC PRESSURE FROM ENGINE-POWER CONTINUOUS CURRENTS

All powers known to us can be classed as derived from two kinds of engines—heat engines and electric engines. The water-wheel or turbine, the windmill, the gas, steam, and oil engines are all heat engines—that is, they are driven by heat expanding a fluid, causing pressure, which moves the engine. The water-wheel is driven by the falling water, which had previously been raised as vapour by the heat of the sun. The windmill is driven by air set in motion by the sun's heat expanding the air, which rises upwards, its place to be filled by cooler air. The steam-engine is driven by heat from fuel producing steam under pressure. Oil and gas engines are driven by the heat liberated on combustion with air in their cylinders.

The electric engine alone can give power without the agency of heat, but as yet no electric engines have been invented to compete commercially with any of the heat engines. What is popularly known as electric power is only the transmission of the power of heat engines by electricity from one dynamo electric machine to another. There is no such thing as a practical electric motive power. We see a mill driven by electro-motors, but if we follow up the inquiry we will find a conductor running away back from the so-called motor to a dynamo, and we will find that dynamo driven by a heat engine, generally a steam-engine, with a boiler and a pile of coal beside it.

The mill is still driven by steam as in days of old, but the power is now distributed and transmitted from the engine to the various machines by wires and electro-motors, which are substitutes for shafting, pulleys, belts, and gear wheels.

The only case of electric power, properly so-called, known to electricians consists of a primary galvanic battery driving an electric motor. A primary battery and an electric motor is *the only truly electric engine* known. The primary battery, however, produces electrical energy, as we have seen in Chapter II., only at enormous cost per horse-power, while a heat engine driving a dynamo produces electrical energy at a very small cost; in fact, for £1 spent in pro-

duction on a heat plant, we would require to spend about £30 to get the same amount of energy from the purely electrical plant. Therefore it is, that at this date the combined heat engine and dynamo is the universally applied machine for supplying electrical energy on a large scale cheaply.

To the philosophical electrical engineer nothing is prettier than to see the true electric engine silently, without smoke, heat, vapour, or dirt, exerting its power, and that with great economy of conversion. But until a cheap, practical, primary battery is discovered, something totally different from present types, the electric engine is impracticable.

This view of the matter is illustrated in the two diagrams on Plate IV. The first figure shows the present stage in electric motive power. A is the coal pile, B is the engine and boiler, C is the dynamo converting the engine-power into electrical energy, and D is the motor reconverting the electrical energy into power. A gas or oil engine may be substituted, or a windmill or water-wheel; the same process is required.

As the heat engine gives off its energy by motion, we are compelled to use something in motion to convert its energy into electrical energy. The want of information on these points was recently exemplified in a leading newspaper in a leading article on electric traction on street railways, by an otherwise well-informed writer. He said that before long our great railway magnates would have to choose between "coal and electricity" as their motive power, evidently oblivious of the elementary fact that all electric traction has for its motive power coal and steam-engines. Perhaps more coal is needed for electric traction than for direct traction by steam locomotives. But the electric is preferable and more economical in every other way.

The amount of potential energy in the coal is very great, and the efficiency of C and D very high; otherwise there would be no electrical engineering to speak of.

The boiler and engine may give out 10 per cent. of the energy in the coal burned. Of this the dynamo will convert 90 per cent. into electrical energy, and of this electrical energy the conductors deliver 95 per cent., and the motor will reconvert and deliver 90 per cent. of energy received to the machine to be driven, E. Every step means a loss; the greatest loss is between the coal pile and the dynamo—that is, in the engine and boiler. We may sum up the efficiency—

Coal pile to dynamo 10 per cent.
Dynamo to motor 85 per cent. = 8.5 per cent. of total.
Motor to machine 85 per cent. = 7.22 per cent. of total.

That is to say, that of all the energy in the coal, only 7.22 per

cent. reaches the machine to be driven. And, theoretically, it can be proved that no improvements on the steam-engine can ever hope to do more than raise its efficiency to about 20 per cent.

In the lower illustration on Plate IV. we have the purely electric engine, in which the electrical energy is delivered direct ready-made from the elements in which it is locked up. The generator is a large battery of cells, in which zinc or other element is consumed by acids, giving up its energy as electrical energy. The losses in such a generator can be reduced to a very small value, so that we might get 80 per cent. efficiency at the terminals of the battery. Hence, total efficiency would be—

Zinc to terminals 80 per cent.

Terminals to E, the machine to be driven, 85 per cent. $= 85 \times 80 = 68$ per cent.

Zinc, however, is a dear fuel, and the acids required to burn it cost more than air, which the coal gets for nothing to burn with it.

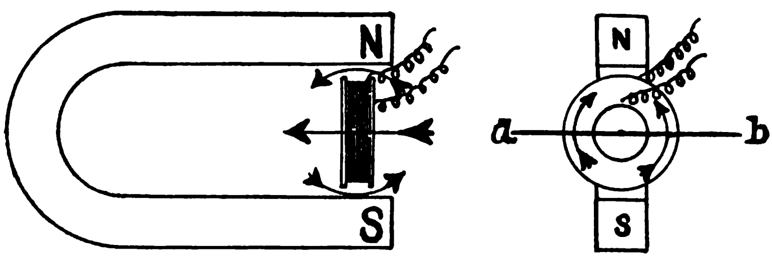


Fig. 122

And the waste products clog up the cells, so that, for these reasons, with all its ideal simplicity and high efficiency, the electric engine can be used only for very small powers.

The induction or generation of electric pressure in moving conductors is therefore at present of first importance to the electrical engineer.

With a horse-shoe magnet and a coil of wire and a voltmeter we can demonstrate the production of electric pressure by motion.

In Fig. 122 we have a magnet and a coil of wire. If we simply thrust a coil of wire between the poles, there shall be induction of pressure, as shown at Fig. 122 in the end view; but as the resulting pressures are in the opposite direction in the lower and upper half of the coil, there could be no current. But if we put the coil on an axis A B, and turned it about this axis, there would be current, for the two halves are cutting the lines in opposite directions.

This is shown more clearly in Fig. 123, where a single coil is fixed on an axis rotatable. In the position shown by the black lines it is cutting no lines of force, as these stream straight across from pole to pole, but as it moves round it will cut all the lines.

The current will be zero in the position of the black lines, then flow in one direction while the coil makes a half revolution; when the current will be nothing again, it will commence to flow in the opposite direction, so that we will have two currents in each revolution and two zero points. We could represent the action by drawing a straight line representing the zero line and curves representing the rise and fall of the currents, the curves above the line representing current in one direction, and those below the line representing current in the opposite direction; or, if we like, let the pressure generated be represented by these curves. This current, first in one direction, then in the opposite direction, alternately, is called an alternating current (see Fig. 124).

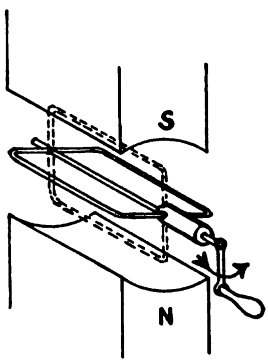


FIG. 123

In order to get the pressure all in same direction it is necessary to commutate these alternate pressures. This is done by fastening to the two ends of the coil a split tube, as shown in Fig. 125, and applying two rubbing contacts, so that the slits are under the brushes at the moment the current changes. By this means we get a current always in one direction, but not continuous, for it is at zero at the moment of change. We can represent this, as shown in Fig. 126, wherein all the curves are above the zero line.

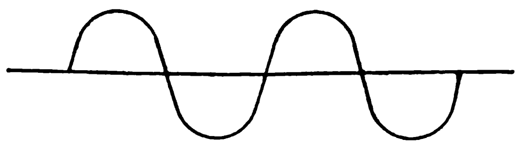


FIG. 124

The coil may have many turns, and instead of an empty coil of wire it may be wound into an iron bobbin of a section shown in Fig. 127, the wire being insulated. This is the form of the old shuttle-wound Siemens magneto machine.

The coils may, however, be wound on a drum (Fig. 128), and divided into two coils with four ends, the coils being at right angles to each other; the pressure in the one will be at its maximum when the other is at zero, and if not commutated would be like the curves in Fig. 129, and when commutated would be nearly continuous, as the pressure would not fall below line F H in Fig. 130.

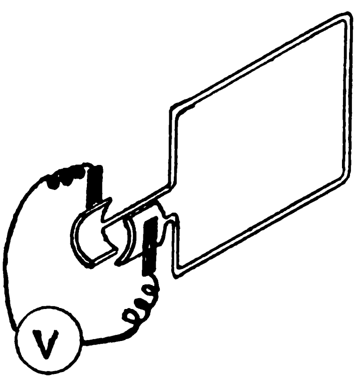


FIG. 125

Continuous Pressure Machines

By multiplying the number of coils and splitting up the commutator into as many pairs of plates, we can get a practically continuous current.

Fig. 131 represents a ring armature with four coils coiled on a ring instead of a drum. The winding and connections shown are those of the common gramme type, the commutator plates being connected to the junction of the coils, and the coils forming a continuous wire over-wound all round the ring of soft iron.

FIG. 126

Fig. 132 shows a ring armature with eight coils between the poles of a magnet. It will be seen that the coils cut the lines of magnetic force twice in each revolution. If the wire was wound on a drum it would be the same—cut twice in each revolution.

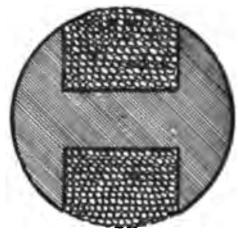


FIG. 127

The brushes are placed so as to make contact with the coils which are not being cut by the lines, coils *a* and *b*. If the winding is followed out it will be seen the three coils to the left of *a* and *b* are in parallel connection with the three to the right of *a b*.

The ring is made up of iron wires or iron washers in order to prevent currents being induced in itself.

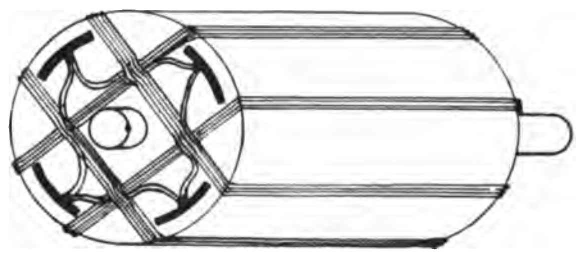


FIG. 128

When the armature is doing no work, no current passing in its armature wires, the lines of force are uniformly dense in the air gaps between the armature and pole faces. But this is not so when the armature carries current in its wires, for then the armature becomes a magnet, with poles N S at the coils which are for the moment under the brushes. This is shown in Fig. 133 for a dynamo, where the effect is clearly seen. The lines

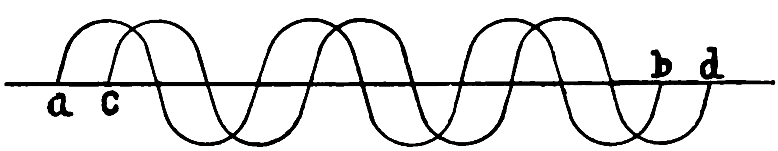


FIG. 129

of magnetic force are shifted and crowded round to join the opposite poles of the field-magnet to the poles of the armature. This effect is, of course, greater, the greater the current in the armature.

FIG. 130

In fact, every dynamo and motor consists broadly of two or more magnets. In the common bipolar machine one magnet is a fixture, the other movable, rotates, and when little or no current is on, the poles of the movable armature are at right angles to the poles of the fixed one, and the lines of force of the fixed magnet are nearly uniformly spread across the air gaps. But immediately current passes in the armature the lines are drawn round, as shown in Fig. 133. This is an important fact, for considered as two magnets the power of a dynamo or motor depends on the sum of the strength of the two magnets. As an illustration of this let the field of the fixed and rotating magnet be equal to 1500 when added together, as they really are, as shown in the figure. Now this sum could be made up by an armature of 750 and a field of 750, or it could be made up of an armature of

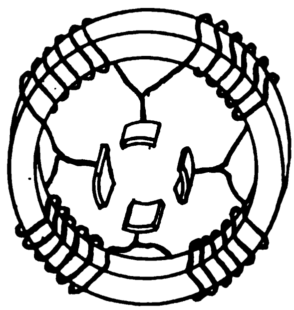


FIG. 131

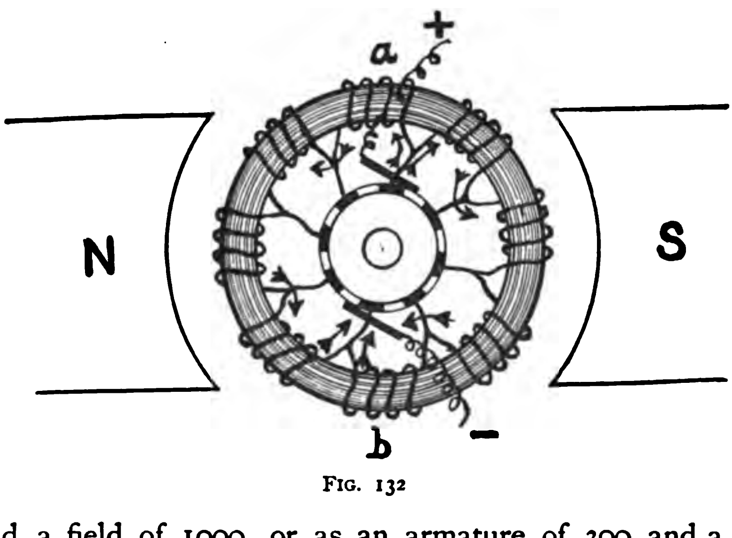


FIG. 132

500 and a field of 1000, or as an armature of 300 and a field of 1200, all at full load.

This distortion of the lines is less the greater the proportion of the total force belonging to the fixed or field-magnet, as can be readily

understood when we consider there is no distortion when there is no current in the armature coils, and that it increases with the current in the armature.

It is therefore desirable in dynamos and motors to make the field-magnet strong and the armature comparatively weak, as magnets.

That is to say, the ampere-turns on the armature should be much less than the ampere-turns on the field-magnet at full load,

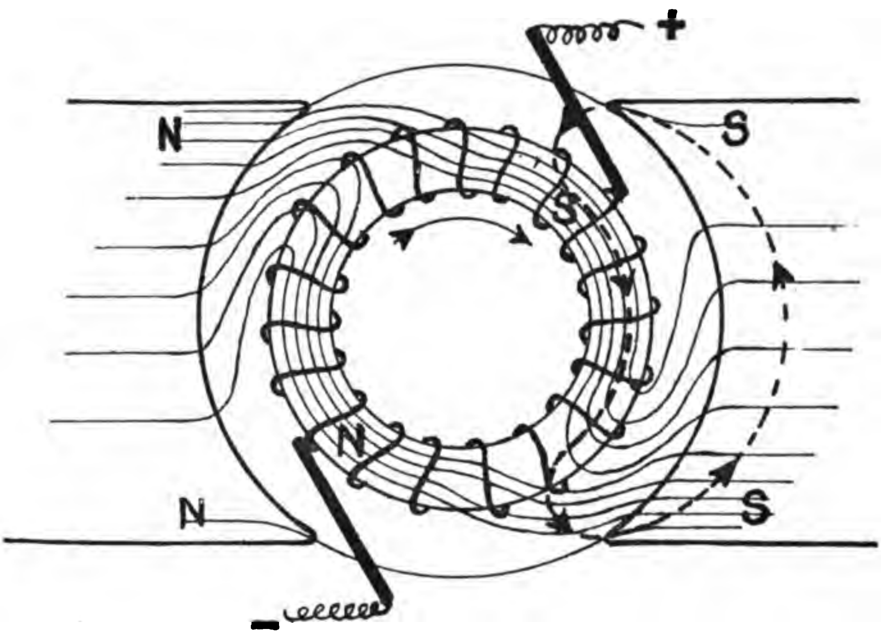


FIG. 133

not more than one-half in most cases; but the ratio varies in different designs, and depends upon the air gap length principally, for the current on the armature tends to send lines of force through the magnet pole-pieces, as shown by a thick dotted line on S S pole.

The pressure developed at the brushes of a dynamo depends on three factors: the speed of rotation, the number of lines of force crossing the air gaps, and the number of turns of wire on the armature.

N represents the speed in revolutions per minute.
Z the lines of force in the air gaps total.
Nt the number of turns of wire on armature.
E the electric pressure at the brushes.

Then, $E = N, Z, Nt, 10^{-6}$.

The 10^{-6} is a short way of writing a long number; it means dividing by 1,000,000. Suppose we have it given to multiply

4.35×10^{-6}, it would become 0.00000435; that is, we shift the decimal point six places.

If the index, as the little figure is called, is written simply 10^6, it means the whole number is to be multiplied by 10 as many times as the index indicates; thus, 4.35×10^6 would equal 4,350,000, moving the decimal six figures.

The common type of ring armature for small machines is shown at Fig. 134, built of ring stampings of annealed iron and carried on

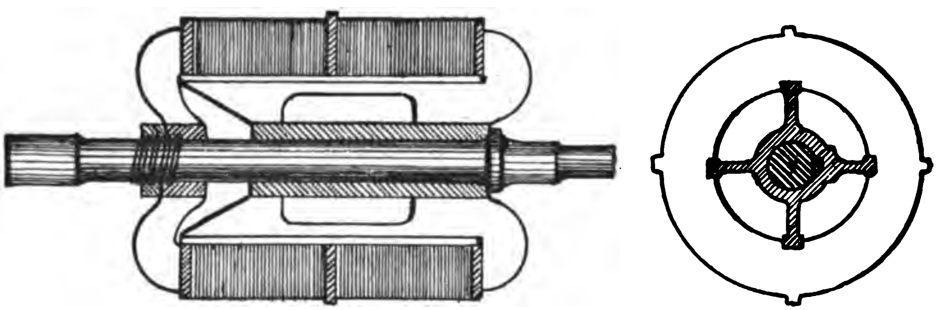


FIG. 134.—Ring Armature

gun-metal spokes. Three insulating washers, one at each end and one in the middle, have projecting horns for driving the conductors.

Fig. 135 shows the common drum armature core with a view of one of the stampings.

It may be as well to refer to the methods in use for calculating

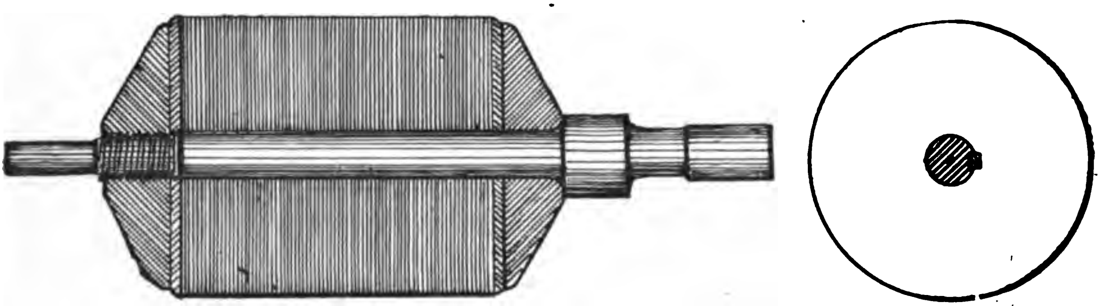


FIG. 135.—Drum Armature

the details of a continuous current dynamo or motor. There is a hiatus in the processes, for no direct method for finding Z or Nt, the unknown quantities, has yet been given. From one authority on dynamo design we quote: "The determination of the best diameter and length of armature, without reference to other designs or machines previously built, can only be effected by a method of trial and error."

This is true. The consequence is that in a new design dimensions are found by expensive experiments. But this ought not to be the case.

There can be no excuse for such a method as the following. An armature is required for a given output, find Z or Nt, and the dimensions of the field-magnet. This is how at present we proceed, "After a preliminary estimate we are led to allow 6 volts loss at full load on armature, and to determine upon 234 as Nt." But as to what the preliminary estimates were, or how determined, nothing is said.

We must now consider the generation of electric pressure by a continuous cutting of lines of force in one direction. Machines made on this principle are called unipolar machines or non-polar dynamos. The latter is by far the best term.

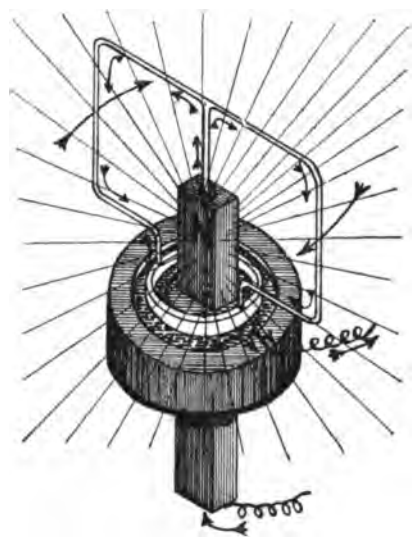


Fig. 136

The simplest machine of this kind is shown in Fig. 136. A magnet has a wooden trough of circular shape fitted about two-thirds up from the lower pole, with mercury inside the trough; a hole is made in the magnet at the top, also containing mercury.

A bent copper wire is pivoted at the bend so as to rotate freely and make electrical contact with the mercury in the hole. The lower ends are riveted to a thin copper ring floating freely in the mercury. If now the wire is spun round on the pivot a continuous current is produced when we connect the mercury trough and the magnet through a circuit, say a galvanometer. This current is due to the wires cutting the lines of magnetic force continually in one direction.

If an electric current is sent up the magnet and down the copper wires and out by the mercury trough, the wires will spin round as a motor, beautifully showing the reversibility of the dynamo: by applying power it gives current, by applying current it gives power.

This elegantly simple method of producing continuous electric currents has fascinated every electrician, and many schemes have been proposed to make a practical machine on this principle. The result of all the labour has hitherto been to produce machines of 2 or 3 volts pressure and very large currents, useful for electro metallurgy and electrolysis only.

What has baffled inventors has been the impossibility of getting armature conductors in series on the armature; every attempt at this has failed, hence the non-polar machine remains at this date as a dynamo with only one conductor on the armature.

The latest and best machine of the kind is one made by Messrs. C. A. Parsons & Co. It is still a one-conductor machine, but as it is driven by a steam turbine at a high rate of speed, 8 or 10 volts may be obtained.

Fig. 137 shows this machine partly in section. C is a soft-iron cylinder or bar on which is threaded a copper tube *d d*. Over its middle part it is mounted on two bearings with a pulley for driving.

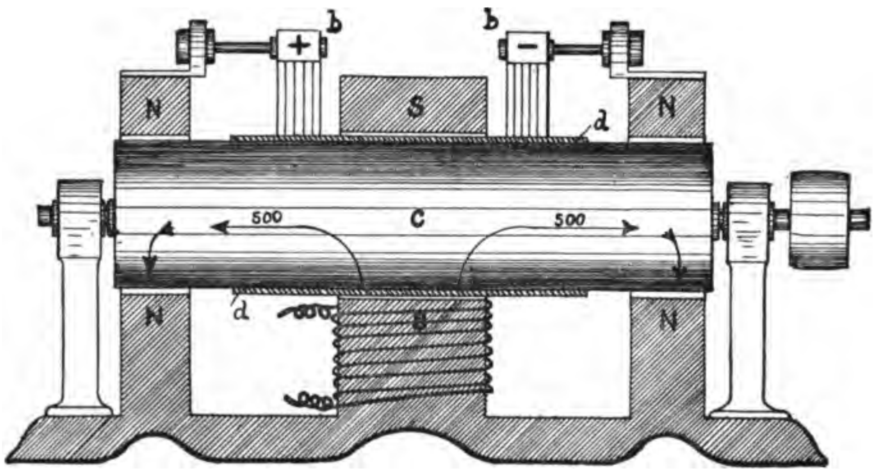


Fig. 137.—Non-Polar Dynamo

A three-poled magnet is applied, one pole in the middle and one at each end. An exciting coil is fitted over the middle pole, so that the copper tube revolving continually cuts the lines in the same direction, and a current at a few volts pressure is produced and collected by the brushes *b b*.

The great advantages of these machines are, first, no laminations are required in the armature, the armature is soft iron solid, and no commutator, that source of great expense and no little trouble in bipolar and multipolar dynamos. These two advantages are so great that attempts are still being made to get out a practical machine at high voltages. And it may be here stated that the author has found a solution of the problem; but it cannot be given here until fully proven.

Messrs. Parsons' machine is here illustrated joined to an electromotor, a combination whereby, say, a 250 volts supply can be

reduced to 5 or 6 volts for electrolytic work. Such a combination is called a motor generator.

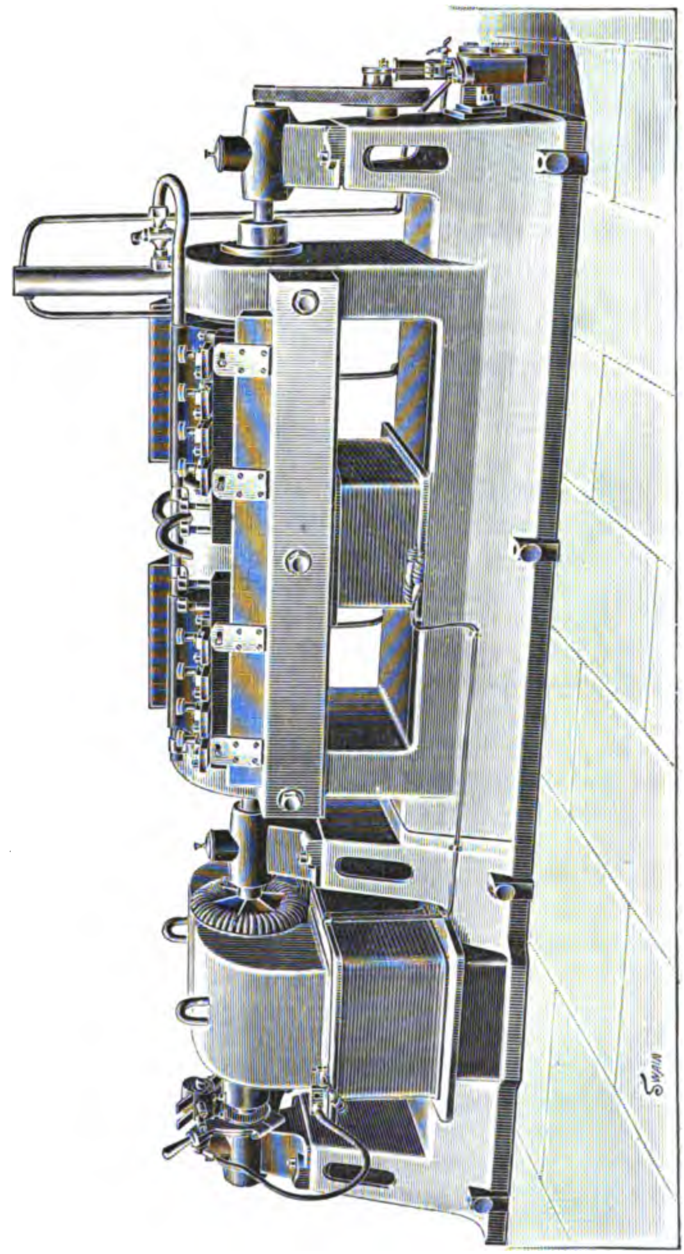


Fig. 138.—Parson's Motor-Generator, with Non-Polar Dynamo

As to the power of these machines, Professor Forbes made one with an armature 6 inches diameter, 9 inches long, which gave

2 volts, 5000 amperes at 2000 revolutions per minute. Assuming a 6 inch bar to take 500 lines of force in this machine—

$$Z = 500,$$
$$N = 2000,$$
$$Nt = 1;$$

hence $$500 \times 2000 \times 1 \; 10^{-6} = E = 1 \text{ volt.}$$

But there are twice 500 lines cutting the tube; for 500 go to the left N. pole and 500 to the right N. pole (see Fig. 164). Thus we get 2 volts.

The large multipolar dynamos with huge laminated cores weighing tons, and immense commutators of exceedingly great expense in making, which are now in use, are bound to be superseded at no distant date by something on the lines of the non-polar dynamo.

The Ferranti and Hookham electricity meters are essentially non-polar motors. And the magnetic brakes used in all motor meters are also non-polar generators. See special Plate No. VII. for illustration of the first practical unipolar dynamo, having a tubular armature over each pole of a horse-shoe magnet.

There are some glimmering prospects that continuous currents of electricity at any desired pressure shall be generated direct from coal or other fuel, without the intervention of any machinery, and that we have to look to the chemist, instead of the engineer, for future improvements. The thermopile does not meet the problem, as it is only a heat engine.

In all attempts to obtain electrical energy direct from fuel, it must never be forgotten that there must be no heat about the process; any heat developed is so much loss. Energy is convertible from one form to another, but only on the down grade is it profitable. Energy is graded; heat is the lowest grade, to which all energy, once liberated, falls. Electrical energy is of a higher grade, falls to heat, and is so lost. Chemical affinity, or the energy locked up in the elements, is of the highest grade; it can be converted into electrical energy, and then into heat, as is done when we heat a wire by a current from a galvanic battery, or the energy may be at once converted into heat by combining, as when hydrogen and oxygen are exploded. If electricity is to be had direct from the elements, the energy must not be allowed to run away as heat, that is, to a far lower level than electricity in the scale of energy.

This is a fair example of the present procedure in determining the details of the design of an armature.

Here V = revolutions, instead of N in our formulæ.
and N = flux, instead of Z.
and S = number of turns of wire on armature, instead of Nt.

Cast-iron Housing

Primary ready for winding

Primary completely wound

Secondary Core

Secondary complete

Type "C" Motor complete

CONSTRUCTION OF A WESTINGHOUSE TYPE "C" MOTOR

Example of Calculations

"In the case of a 25 K.W. dynamo, the loss by heat is $C^2R = 2.5$ per cent. of the output = 625 watts. Hence the armature should have an external surface of 625 square inches. With no special mechanical condition to meet, the best cross-section for a Siemens armature core is square; hence $d = 11.5$, and sectional area 132. The insulating material between the plates and the space occupied by the shaft compose about 20 per cent. of the core in the average armature, leaving 80 per cent. of iron; hence the effective area of this core is $132 \times .80 = 106$ square inches = 684 square centimetres. If B_a is 10,000 C.G.S. lines per square centimetre, N is 6,840,000 C.G.S. lines. At a periphery speed of 3000′ per minute, the number of revolutions per minute is V = 1000. Then from the formula

$$S = \frac{60 \times E \times 10^8}{6,840,000 \times 1000}$$

is derived at once the number of conductors on the periphery of the armature. If 125 volts be desired at the brushes, S = 110—, or there must be a total of 55 turns on the armature. On account of the loss of pressure in the armature, &c., it is desirable to add a few extra conductors, and for the best forms of winding an even number of turns is desirable. Fifty-six turns may therefore be chosen, and these can be wound on the core as 56 coils of one turn each, 28 coils of two turns each, &c. Choice must rest upon the conditions likely to give the least commutator sparking and the most compact winding. The armature under consideration should therefore be wound with 56 coils of one turn each."

From the foregoing it seems all depends on the watts to be lost in the armature winding. It takes no account of many points of far more importance; in fact, it is a process used for want of one which would directly determine Z from the output required.

$$Z = 1140,$$
$$Nt = 110,$$
$$N = 1000;$$

hence $1140 \times 110 \times 1000 \times 10^6 = 125$ volts.

Those who make machines choose different designs, but in most cases the formula for finding Z used by the author—

$Z = \sqrt{K.W.\ 12,500 \times 2}$, will give good results, and

$Z = \sqrt{K.W. \times 12,500 \times 3}$ will give better results.

The constant 12,500 is for 1000 revolutions per minute and must be increased in proportion as the speed is decreased. Thus a speed of 500 would raise constant to 25,000.

CHAPTER VI

ALTERNATING CURRENT MOTORS AND GENERATORS

We have seen that the machines for generating electric pressure are, all except the non-polar dynamo, machines in which the electric pressure is alternating in the coils of wire on the armature. When a wire sweeps along in the air gap its pressure is in one direction when the coil is moving in front of a N., and in the opposite direction when moving in front of the S. pole; hence, to get a continuous current from these machines a commutator is used in order to turn them all into one direction. With a single coil we use a split tube commutator, so that the + end of the coil is always in connection with the positive brush, and the negative end of the coil always in contact with the positive brush, and we also place the brushes so that they slip from one section to the other at the moment when the current is reversing.

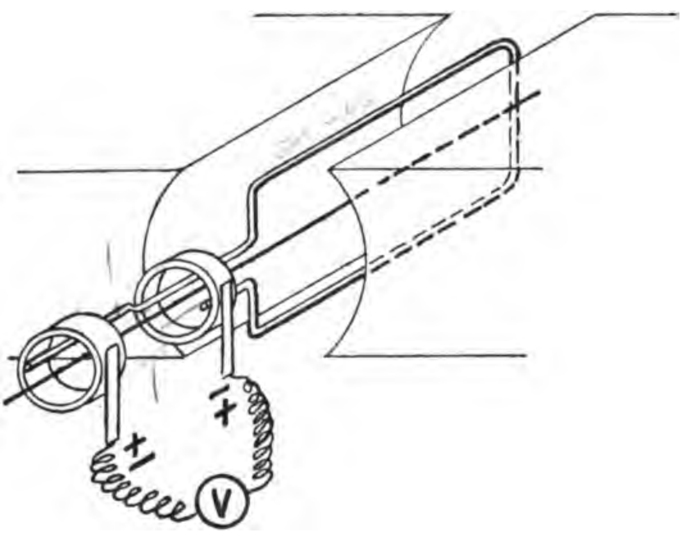


Fig. 139

If we rotated a loop of wire in a magnetic field whose ends were attached to two plain copper rings on the same shaft and applied two brushes, we would get an alternating current, as in Fig. 139.

The simplest alternating current generator is a continuous current dynamo, with two copper rings insulated on the shaft and connected to two diametrically opposite points of the armature winding if it is a two-pole dynamo. This is shown in Fig. 140. The ordinary brushes and commutator are used to excite the machine, and, in fact, a continuous current can be drawn from one end while an alternating current is being drawn from the other end at the copper rings.

As the armature revolves the copper rings will be alternately positive and negative, the maximum pressure being at the moment when they are connected to the brushes through the winding, and the reversal or minimum at right angles to the line of commutation.

The frequency, that is, one positive and one negative impulse, will be one ∽ per revolution; if the speed is 2000 the frequency will be 2000 per minute or $\frac{2000}{60} = 33.3$ per second.

The maximum E.M.F. shall be the same as that at the brushes on the continuous current side, say 250 volts, but the average volts will be less, because the pressure waxes and wanes from zero to 250 and from 250 to zero again. The volts measured on both sides with a voltmeter reading correct for both alternating and continuous current shall be as 1 is to the $\sqrt{2}$; the $\sqrt{2}$ is equal to 1.41, so that to get 100 volts on the alternating side we would require to get 141 volts on the continuous side. In the case of a 250 volt machine the proportion would be the same, $\frac{250}{1.41} = 177.3$ would be the volts from the alternating side; or if we required 250 volts alternating, then we would require to make the machine 250× 1.41, or 352.5 volts continuous pressure.

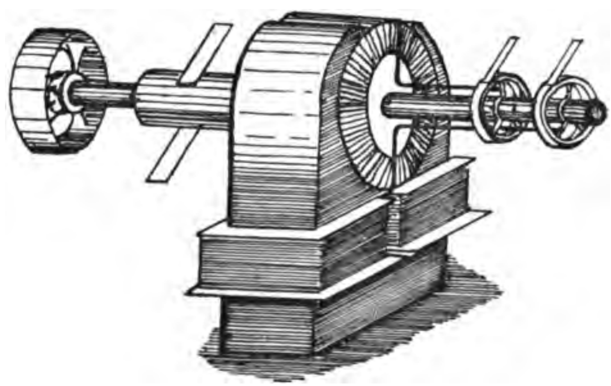


FIG. 140

Now we can calculate out a continuous current machine for any voltage, hence we can just in the same way calculate out this alternating machine, making the above corrections, and the output in kilowatts will be the same for both sides of the machine separately; for although the volts are less on the alternating side the current may be greater for the same heating of the armature, for it is not continuously "on." This machine is the simplest alternator, and gives a single-phase alternating current, that is, in one alternating circuit. But we can take two alternating currents from this armature. If we connect another pair of rings to two points at right angles, as in diagram, Fig. 141, to the first two, we will now get two currents in different phases alternating; one will be at its maximum strength when the other is at its minimum, or zero value. The one is said to be in quadrature to the other when they follow each other at

right angles, one zero when the other is full value, and the pulsations or frequency are the same; but they are not co-phasedly synchronous. When two alternating currents are co-phasedly synchronous they keep step, the maximum and the minimum occurring simultaneously and of same sign.

They are called "Two-Phase Currents" popularly. Properly speaking, there are two currents in different phases, *i.e.* in quadrature.

The E.M.F. would be the same as already found in each circuit.

Then we could connect three wires to such a machine to three rings connected at points 120° apart from each other and get three currents, each differing in phase from the other by 120°, and thus get three currents in different phases but with exactly the same frequency and pressure.

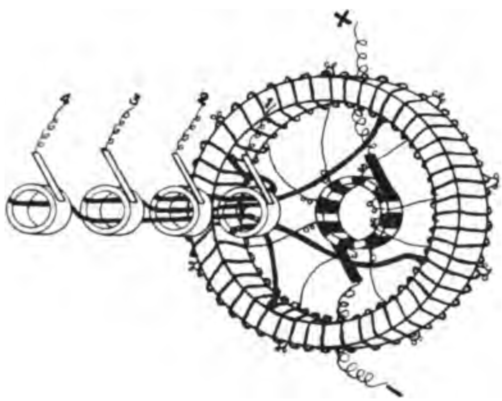


FIG. 141

Such a machine is very useful in laboratories for electrical engineering, also in other experimental work, also as convertors to be described later.

For experimental work and for manufacturers who make apparatus such as arc lamps, motors, ammeters, voltmeters, and the like, and require to test them, whether alternating or continuous, and at various frequencies, one machine is sufficient for all purposes. It should be a multipolar machine with at least six or eight poles, so that at a speed of 1200 per min. the frequency would be 20 ∽ per revolution, and with eight poles 4×20 would be the frequency—namely, 80 per second.

If used in a factory it can have a three-cone speed drive 1200 for 80 ∽, 900 for 60 ∽, and 600 for 40 ∽ frequency. Few commercial apparatus would not come within this compass. The field winding should be capable of coupling up in two parallels and three parallels to suit the speeds.

The day has arrived when small alternators may be generally discarded. Continuous current is so easily obtained and suitable for all purposes that engineers may not now give small alternators that attention they at one time required. One case where the alternating generator of special design would still be useful is in ship-lighting. Low pressure, 110 volts or less, is ample and preferable to a higher pressure; safety is

the first consideration, the saving in copper effected by using 200 or 250 volts would be nothing to speak of in a ship plant.

For this purpose an alternator, self-exciting, coupled to a high-speed compound engine, is a far hardier plant than the continuous current plant in the same circumstances, and it should be a machine giving two currents in different phases, in quadrature, so that motors without commutators can be used for pumping, hoisting, fans, and so on.

A frequency anything between 40 and 50 is found to be best for most purposes. If these frequencies are desired at a lower speed, more poles must be employed in the machine.

Electric welding requires in most cases an alternating current of low voltage and large volume. This is best obtained by a special machine of this type, shown in Fig. 140, giving about 141 volts continuous for exciting the field from a small commutator, and 100 volts alternating from two rings of copper, and this alternating current is then transformed from a high to a low pressure in the welding machine.

The great future for alternating currents is their use for long distance transmission of large powers, from centres where fuel is cheap, or cheap power available, for which large generating machines are the only ones worth considering. The practice is becoming uniform to use flywheel machines—that is, machines in which the engine flywheel forms the carrier of the magnets, and revolves inside of a circular frame carrying the armature coils.

When we come to require large powers we must have multipolar fields and a different form of winding on the armature. The winding consists of as many coils as there are poles on the magnet when a single-phase machine is required, twice as many coils for two-phase currents, and three times as many for three currents. We may consider the single-phase alternator first. The poles are usually equal in breadth to the spaces between them, as shown in Fig. 142, where a portion of a flywheel with outward projecting poles are shown inside an armature carrying coils on its inside face. These coils when laid in place make spaces and wires equal in breadth all round—that is to say, the pitch of the wires and spaces are equal to the pitch of the poles. This is shown in Fig. 143. A ring armature is shown in Fig. 144 by diagram showing the winding and spaces.

In a multipolar machine like this, and with all the coils in series, we use p in the formulæ for the number of pairs of poles, and K, a constant, depending on the disposition of the wire on the armature. If the poles and coils are equally pitched, and laid in the armature in slots, K is about 2 in value; hence we get $E = K, p, Z, Nt, N, 10^{-6}$, the former formulæ for continuous currents, with constant K, and number of pairs of poles, p, additional.

This formulæ gives only an approximate result in practice, for there are actions in these machines which cannot be reduced to figures; but the results are very nearly correct, especially in machines worked with a very great magnetic flux and small armature winding, great Z and small Nt, in the armature.

Alternators should not be worked at great magnetic flux density

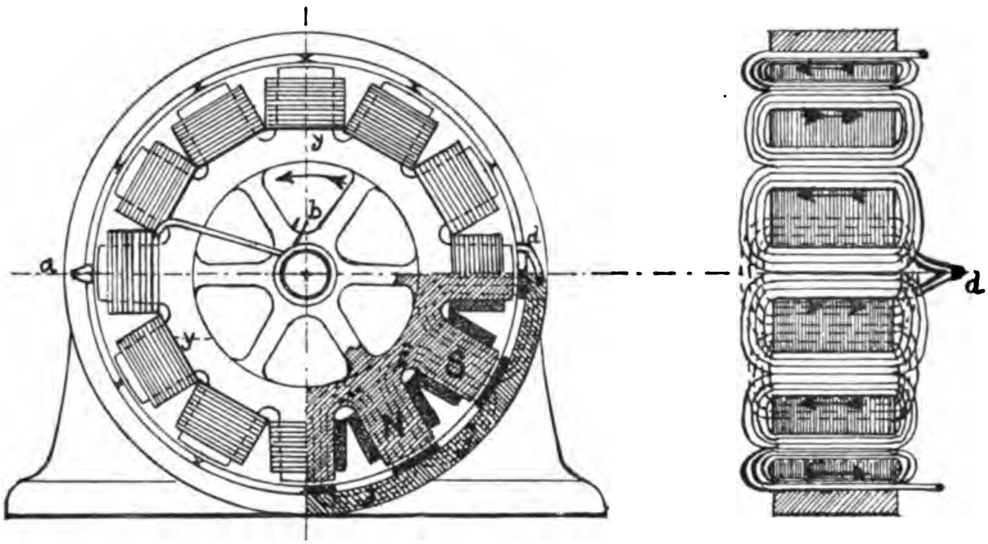


FIG. 142

in the armature core, for at high density and quick frequency there is a great loss by hysteresis in the iron, a loss due to internal electrical currents. An armature which hums loudly when loaded is, as a rule, worked at too great a density for the frequency used. The density, or B, in the armature core should not exceed twelve English lines of force per square inch of magnet section at the very

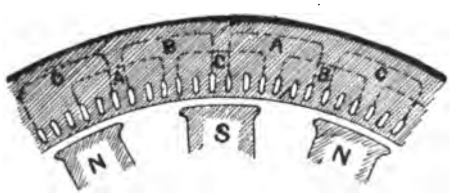


FIG. 143

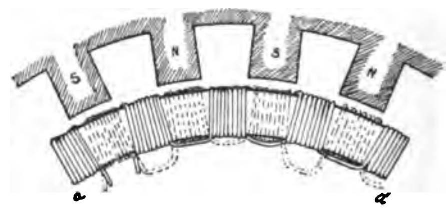


FIG. 144

utmost. Even at that flux density, with 100 ∽ per second, 6 horse-power per ton of iron is lost. Alternators require, for this reason, to have far greater proportion of iron in their structure than continuous current generators. In the formulæ given for calculating E, the Z is the flux total from one pole, *i.e.* between one pair.

Hence in a ten-pole machine at 360 revolutions per minute, and a flux of 500 between one pair, we get

$$2 \times 5 \times 500 \times 500 \times 1000 \times 10^{-6} = 2500 \text{ volts},$$

there being 500 turns of wire all round the armature.

Referring now to Fig. 142. If the armature is to be used for a single alternating current the spaces are empty between the wires crossing the inner face of the armature, the coils being fastened to this inner face. By laying on two series of coils overlapping, so that the wires of the one series fill the spaces of the other series, we shall get two currents, and their difference of phase shall be in quadrature, commonly called two-phase currents; the one shall be at a maximum at the moment the other is at a minimum value, for the wires of one series shall be immediately over the poles at the instant the wires of the other series are between the poles of the field-magnets. This same thing is shown in Fig. 144, which shows a portion of a ring armature inside a field-magnet, with inward projecting poles. If wound with twice as many coils as there are poles, say in a twelve-pole machine, twelve coils under the poles and twelve coils between the poles, then we must couple the twelve under the poles in one series and the twelve between the poles all in another distinct series, and get two currents in different phases.

Fig. 145

The celebrated Gramme[1] made a machine like Fig. 145. Wound all over on the armature he found that the coils under the poles differed in phase from the other coils, and connected his circuits so as to get all the coils of same phase in one circuit and all the coils of different phase in another; in fact, his machine generated two currents in quadrature.

In Fig. 143 a portion of a ring external armature is shown, with a portion of a flywheel magnet for producing three currents in different phases. Here one is at its maximum, A′, say positively, while B′ is at half full value positively, and C′ half full value negatively. Then A is full value negative, B half value negative, and C half value positive.

It will be perfectly clear now that alternators, whether for one current, two currents, or three currents, are all the same, only the armature coils being differently subdivided and connected.

[1] *Vide* Prof. S. P. Thomson's "Polyphase Machinery."

The single-phase machine, however, will give only half the output, for half the armature space is empty.

In the history of the alternator, opinion has swayed from side to side upon the question of ironless armatures and armatures with iron. British makers inclined to the ironless type at first. Siemens, Ferranti, Mordey, and Crompton machines were all for some time ironless discs. But the armature consisting of thin iron stampings carrying the conductors has many advantages, and now the universal practice is to use stampings like Fig. 146 to build up armatures, the conductors being laid in slots and connected in the proper series and groups to give single, two, or three currents as desired.

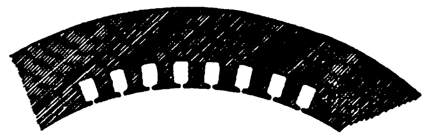


FIG. 146

Multiphase machines actually generate pressure in two or more distinct windings, and these windings can be used separately in connection with separate external circuits, but then in the case of two circuits we would require four line wires, and in the case of three circuits six line wires.

But the circuits can be connected on the armature, and wires saved, by several methods.

Fig. 147 shows what is known as the star system of coupling three circuits in different phases. It is further illustrated by a simple ring with three coils (Fig. 148); *m n o* are the three terminals of the machine.

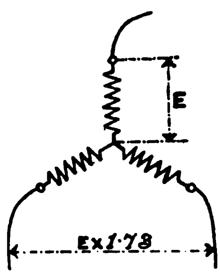


FIG. 147

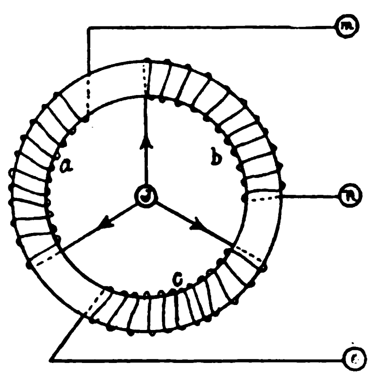


FIG. 148

Another method, the mesh system, is shown at Fig. 149. The coils are shown on a simple ring, as before, at Fig. 150.

Now, the line wires go from *m n o*, and it is to be noted that the pressure difference between the wires is greater than at the terminals of the coils when the coils are coupled as a star, but the current is the same in the coils and external circuits, while with a

mesh coupling of the coils the external currents are greater than those in the coils, while the pressure is the same inside and externally. In the star system the *pressure* in the line wires is equal to that in the coils multiplied by $\sqrt{3}$—that is, 1.73.

In the mesh coupling the *current* carried by the coils is multiplied by 1.73 to get the value of the current in the line wires.

The same applies to two-phase circuits. Here we make one wire a common return, in fact, a three-wire system. The maximum

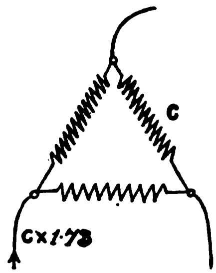


FIG. 149

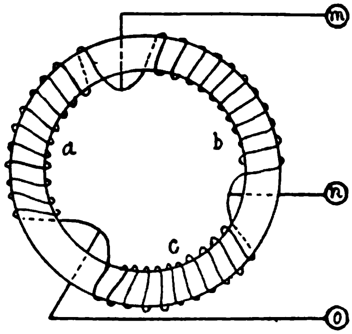


FIG. 150

current in the middle wire will be equal to the current in the other two wires multiplied by $\sqrt{2}$—that is, by 1.41. Fig. 151 illustrates this system ; *a b* are the two outer wires in the junction of the other two.

In a continuous current system the pressure between the outer and inner wires is half the pressure between the outers—that is, if the outers differ by 200 volts, the difference between these and the

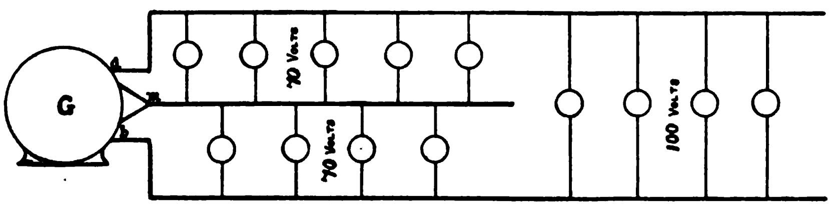


FIG. 151

inner wire is 100 volts. That is not so with a two-phase three-wire system. If we add the pressures between the outer and inner wire the sum will be greater than the pressure between the outers; in fact, it will be 1.4 times greater, so that if the outers differ in pressure by 100 volts, the difference between *a* and *b* would be only 140 volts—that is, $\frac{100 + 100}{\sqrt{2}} = 140$.

A mesh system of coupling a two-phase system is shown in Fig. 152. To feed 100 volt lamps the pressure between *a a* and *b b* would be 141.4 volts, and the current in the wires 1.41 times that in the lamps, so that it need not be considered as a practical system.

Two-Phase Star and Mesh Work

A star system of two-phase connections is shown at Fig. 153, with the junction joined by wire to the lamp circuit junction at *j*.

There will be required to feed 100 volt lamps 200 volts from a to a^1 and b to b^1, and 141 volts from a to b or a^1 to b^1.

The two-phase system is not nearly so useful as the three-phase. It requires heavier wires and is difficult to balance.

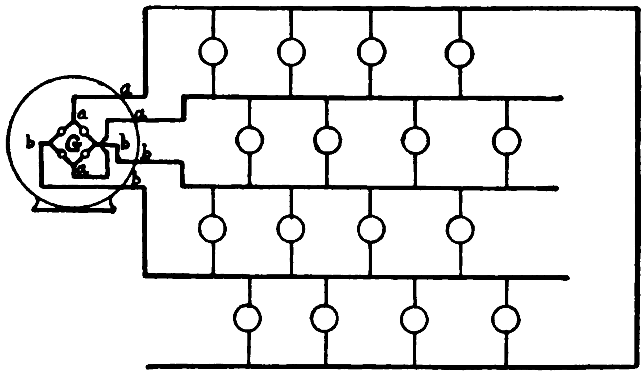


FIG. 152.—Two-Phase Mesh System

The three-phase star coupling (Fig. 154) with the junction earthed is by far the best system of working; hence most multiphase alternators have their coils coupled in star connection.

The generators being coupled in star connection, the consuming apparatus, motors or lamps must also be coupled in star.

M. Dobrowolski had lamps made, both arc and incandescent, in which there were three carbons, so that they could be star connected to a three-wire system of three phases.

But the chief use for multiphase currents is to carry large quantities of energy over long distances, from some cheap source, to large consumers, the energy carried at 20,000 volts or more, and transformed into continuous or alternating current, and delivered at 400 or 500 volts. It is only due to its facility in conversion from high to low pressure that a multiphase system is of value.

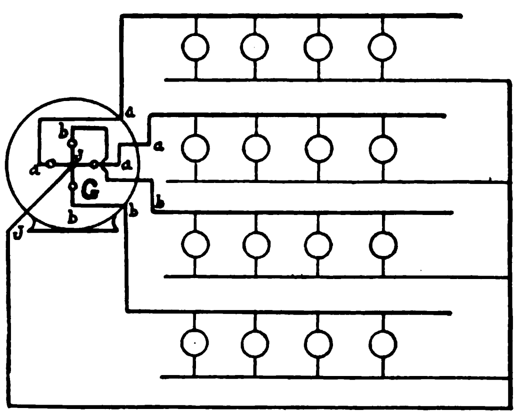


FIG. 153.—Two-Phase Star System

This easy conversion is, however, of very great value in practice, hence we must consider the use of alternating currents and alternating apparatus for every purpose for which they can be advantageously applied.

The alternating current system was originally introduced at a time in the history of electrical engineering when things generally were in a commercially undeveloped state in the electrical world.

It offered a ready means of supplying current to customers few and far between. A high-pressure system of mains was run up, often overhead like telephone wires; a transformer was fixed on the consumer's premises, which converted the high pressure to low pressure and delivered the current.

Incandescent lamps were then ranging in pressure from 50 to 120 volts—120 volts was then considered very high pressure for a consumer to use—and the three-wire system was imperfectly appreciated or misunderstood by the then advisers on these matters; hence the alternating system was adopted in many places for distributing electricity for lighting purposes, and, once established, it has in most cases been adhered to, not because of its having proved to be the best system, but because it would cost an enormous amount of money to scrap these systems and put in another. When first introduced the alternating system had many features to recommend it for the then existing conditions for supplying electric lights.

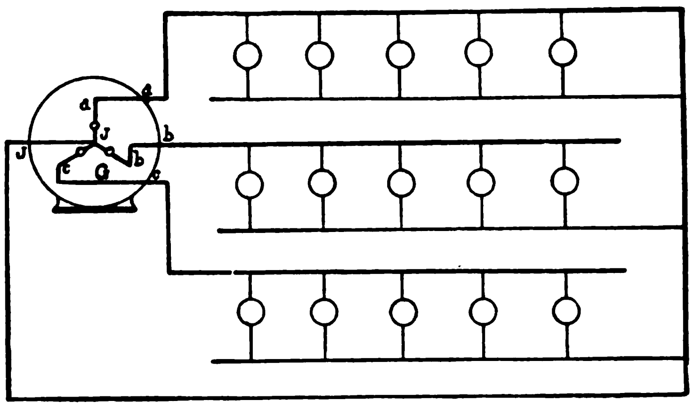


FIG. 154.—Three-Phase Star System

And still in some places, such as outlying suburban districts, it can be used with advantage in supplying electricity for lighting. But in crowded centres like those in London, Glasgow, Edinburgh, and other cities, the three-wire system of continuous current supply at 500 volts between the outers and 250 between the outer and inner wires is far better; for the bulk of the energy is delivered within a comparatively short distance of the generators, one set of supply mains with feeders are used instead of two sets with transformers, as in the alternating system, and continuous current motors can be used with all their advantages over any presently known alternating motor. And, for electric traction, alternating current is only of use to convey the

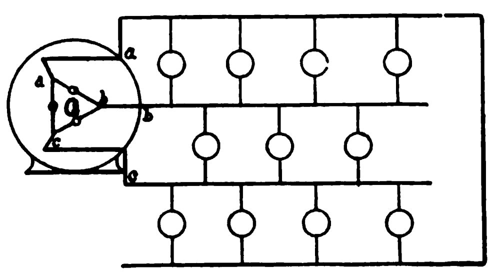


FIG. 155.—Three-Phase Mesh System

large quantities of energy from the generators to distant parts of the line to be converted into continuous current to work the cars.

For power purposes, the multiphase motor is better than the single-phase motor, because it is self-starting under some load, while the other requires a starting device even under no load; while the continuous current motor starts under many times its full load.

The alternating current motor and motor generator must be used in the large distribution schemes, and many small motors are required for the existing established alternating systems. The electrical engineer must therefore study these machines and their possibilities.

The continuous current motor has not as yet been specially mentioned in this work because there is nothing to distinguish it from a continuous current dynamo; the best practice is to make them alike. In later volumes special designs for special conditions shall be considered, but still the continuous motor and generator are essentially alike.

The same can be said in a sense of the alternating motor, but that only of one type, that which is known as a synchronous motor. Any alternator can be run as a motor on any alternating supply, but it must run synchronously, that is to say, its frequency must keep step with the frequency of the supply. The frequency is equal to the number of pairs of poles multiplied by the revolutions per second.

To find the speed of synchronism for a synchronous motor in revolutions per second, divide the frequency of the circuit upon which it is to be worked by the number of pairs of poles, $\frac{\backsim}{P}$; say $\backsim = 100$, and the motor has 5 pairs of poles, then $\frac{100}{5} = 20$ revolutions per second, or $20 \times 60 = 1200$ per minute.

These motors exert great power, are highly efficient, and must of necessity maintain constant speed, as they must keep step with the generator. If they are overloaded they will stop.

They have two objectionable drawbacks: first, they must be excited, or, in other words, their field-magnet must be magnetised by a continuous current same as an alternator requires; and secondly, they must be started up to speed before coupling on to the mains—they will not start to run themselves unless previously speeded up to full speed by some external means. These are serious drawbacks, but still there is a field of usefulness for such machines, and means for starting and exciting them have been found.

A proposal for both purposes has been successfully applied by Mr. Mordey, whose machine (Fig. 156) is here illustrated. The alternator

has a fixed disc armature and revolving field-magnets, and carries on the shaft a small continuous current generator for supplying the current to the magnet coils for exciting purposes.

Mr. Mordey's plan is to use an accumulator to start the machine by driving the little exciter as a motor by the accumulator current; then when the speed is up to synchronising speed, or just a little above that, the current from the external alternating circuit is gradually turned on to the alternating armature, and continuous current from the exciter turned on to the field coils, the alternator will drop

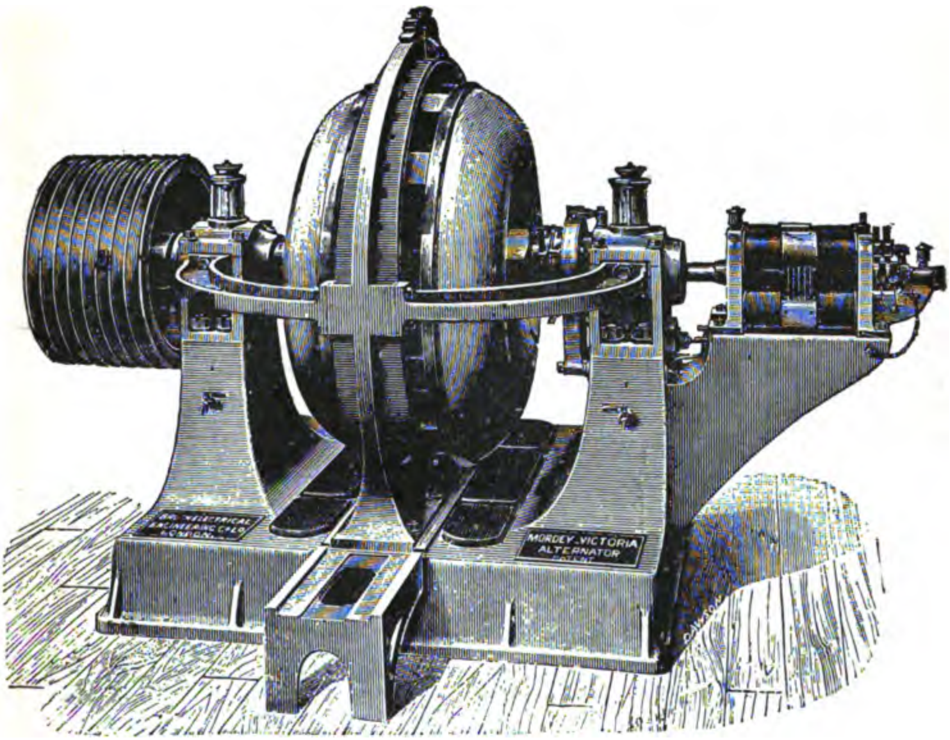


FIG. 156.—Mordey Alternator

into step, and then the accumulator is cut off and full pressure turned on the motor. The accumulator is charged from time to time from the exciter circuit when required.

The exciting current in these machines must be adjusted to get the best effect. A shunt or separately excited continuous current motor can adjust its own speed automatically to correspond to the strength of the field, but a synchronous motor cannot alter its speed; hence we must adjust the exciting current in a synchronous motor. To find the best exciting current practically, the motor should be run synchronously at no load on the circuit it is intended to work it

upon, and an ammeter should be placed in the armature circuit of the motor to read alternating currents of a few amperes, say from .o to 10 amperes, then vary the field current, the circuit of which has another ammeter to read the exciting current; it will be seen that the current taken by the alternating motor armature varies with the variations in the field current, and a value will be found for the field current at which the alternating current is a minimum. In this test everything must be quite normal, no extra friction, but simply the machine run free without any load.

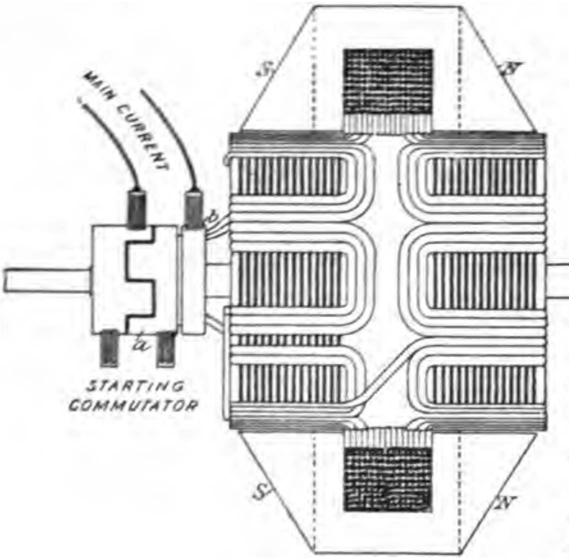


FIG. 157.
Section showing Armature and Field of Kennedy's Self-starting Synchronising Motor

Fig. 157 illustrates a synchronous motor of the author's design. In this machine the starting and exciting are both accomplished by a commutator, the armature is wound double and the poles staggered—that is, the poles on one side are opposite the spaces on the other side (shown Fig. 158); the starting is made by the alternating current acting alternately in each armature winding without exciting the field; when synchronous speed has been reached the alternating current is switched direct to the armature circuit and the commutator then rectifies, that is, commutates part of the alternating current always in one direction through the field-magnet, thus exciting them.

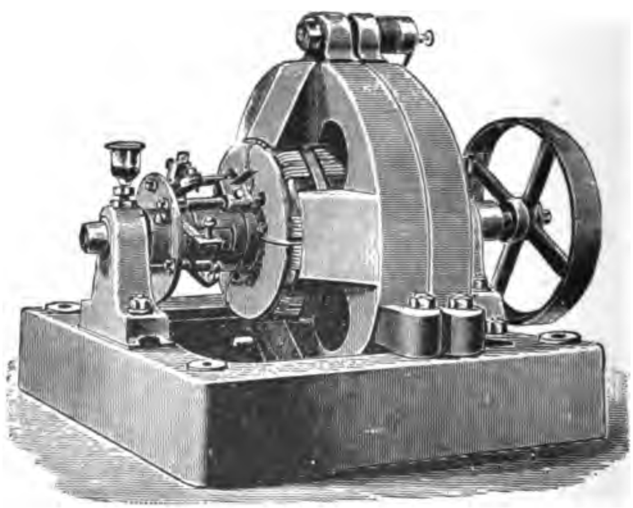


FIG. 158.—Complete View of Kennedy's Synchronising Motor

This machine can also be started by accumulators without any separate exciter. But the motor for alternating currents is the induction motor, so called because the field circuit is alternating and induces current in the

armature, the armature working with that induced current alone. They are made for one, two, or three currents, called respectively monophase, two-phase, and three-phase motors.

Attempts have been made to trace back the induction motor to Arago's disc experiments, but there can be no connection shown between them. Arago only proved what Faraday had already proved—the generation of current in a copper disc moving in a magnetic field, only Faraday moved the disc in the field and Arago moved the field; the currents in the disc would have moved Faraday's magnet if it had been movable.

In Faraday's experiment or Arago's experiment we are dealing with continuous current only, and if there is no motion of either the field or magnet there is no current. And to make anything like a motor on either plan would require brushes and an external supply of current.

Totally different in action is the induction motor, as will be seen by experiments with a third disc shown in Fig. 159. Faraday's disc

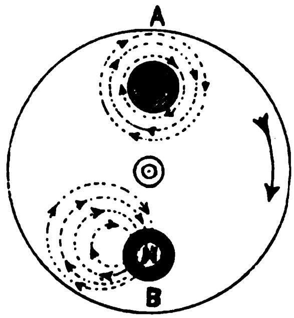


FIG. 159

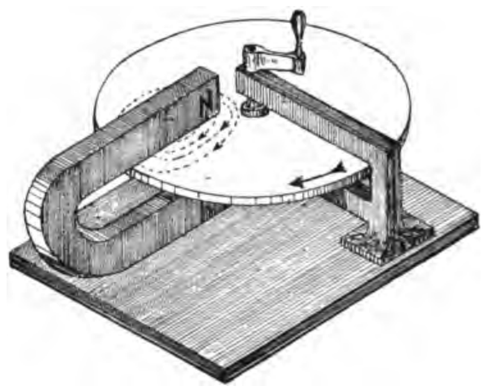


FIG. 160

is shown in Fig. 160, in which currents are generated in the disc as it is rotated, as shown by dotted lines on the disc under the poles. These currents of course tend to pull the magnet round with them. All that Arago did was to put the magnet vertical with its two poles under the disc, and, rotating the magnet, proved the action and reaction between the two. But if we are to arrive at an induction motor we must take another starting-point. With a copper disc, as in Fig. 159, capable of being spun round on a centre, first consider the plate at rest and placed over the pole of an alternating magnet at A; we know that currents will be generated circulating concentric with the pole, as shown in dotted circular lines at A. Now in the Arago and Faraday experiments there are no currents in the disc when it and the magnet are at rest, and cannot be any.

While the currents are flowing concentrically in the disc round the pole there is equilibrium—no tendency of the disc to run round

one way or the other. But spin the copper disc rapidly, and we find, what neither of the eminent philosophers demonstrated, that the disc will go on spinning round as long as we keep up the alternating current in the magnet. And this is due to the shifting of the induced currents with the disc. The currents induced by the alternating magnet are not fully developed instantaneously, but take time to reach a maximum; hence the current lags behind the magnetic impulse which sets it up, and lags so much that by the time the next magnetic impulse arrives on the disc the currents due to the previous impulse have been carried round by the movement of the disc into the position shown by dotted circles at B, that is, into a position where they come right over the pole, exactly where they will receive a push to one side or the other. The dotted circles are to all intents and purposes similar to coils of wire carrying a current.

The secret of the induction motor is this carrying round of the induced current during its growth.

Fig. 161 shows this clearly on a spinning disc over a long alternating pole; the whirl shown was set up when the magnet

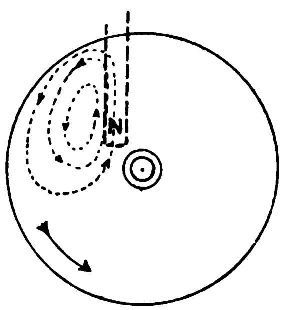


Fig. 161

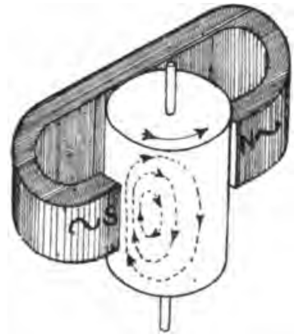


Fig. 162

was a S. pole, and has been carried round so that one side of it comes under the pole when it is reversed.

Fig. 162 shows same effect on a drum revolving between the poles of an alternating magnet. The current in the copper drum has just developed, but the drum has moved round, so bringing one side of the current whirl under the pole, where it will be acted upon by the magnetic flux succeeding the one which set up the current.

No rotary field theory is necessary to explain these motors; it is the rotation of the armature that is the vital motion. Fig. 159 is the disc experiment to which the induction motor alone can be traced, and represents the single-phase induction motor as used in practice.

Now we can similarly explain the two-phase induction motor by an experiment with the same disc of copper. Let a four-limbed alternating magnet be placed under the disc, as in Fig. 163, and

let opposite pairs be coupled up to two current alternating in quadrature, the two whirls of current set up will now be acted upon by the other pair of poles even when the disc is at rest. For by the time the currents have reached their maximum value the two magnetic poles at right angles will have reached maximum also, while the first two are zero. The disc will then be pulled round by the poles, and will now be self-starting; but otherwise the action is the same—the attraction and repulsion of self-induced currents by the magnetic poles.

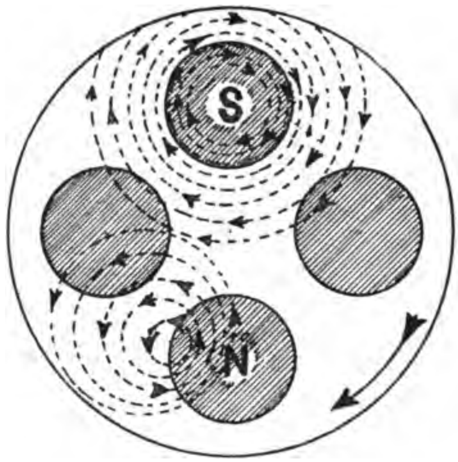


FIG. 163

The revolving pole and rotating field theory is not necessary to explain either the monophase or multiphase motors.

As a matter of fact, two-phase motors have been made by the author and others for heavy work by combining two single-phase motors in which no possible rotation of anything but the armatures takes place. Fig. 164 shows the two armatures with one common winding. They are placed in two separate alternating fields—one excited by the one phase and the other by the other phase. Fig. 165 shows the complete motor.

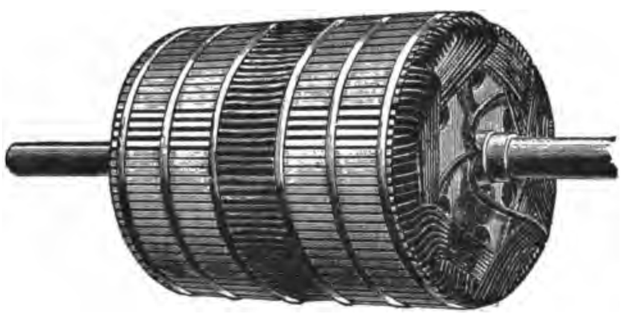


FIG. 164.—Double Armature of Kennedy's Two-Phase Motor

The induction motor consists of two parts — a primary and secondary. The primary receives the primary current or currents, and is usually the fixed part, and corresponds to the field-magnet. It is called the stator. The secondary carries only induced currents, and corresponds to the armature of a motor. It is called the rotor. They are both as a rule cylindrical, and carry the wires in holes or slots near the surface, so that the magnetic resistance is reduced to a minimum. The clearance between the two must be very small.

In small motors up to 5 horse-power the rotor slots or holes carry straight copper bars, joined at the ends by copper rings, as shown clearly in Plates V. and VI.

This is called a "squirrel-cage" winding, and such a rotor is shown in Plate VI., where square copper bars are carried in a laminated armature in slots. The stator is usually enclosed in a cast-iron case, and is wound with insulated wire in the slots to produce two or four or more pairs of poles, as shown in Plate V.

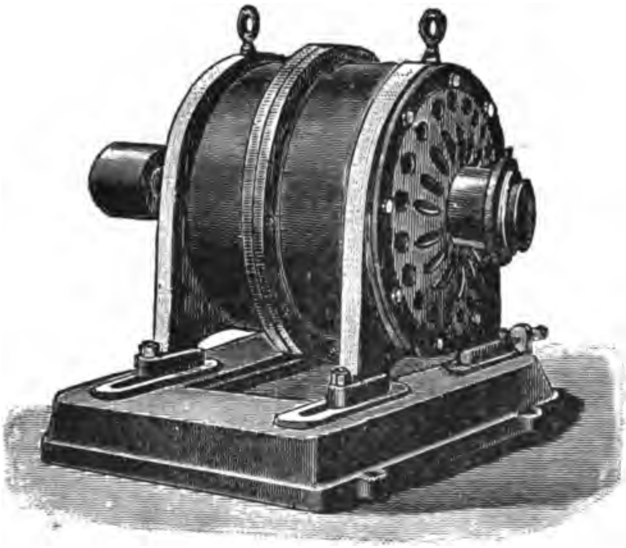


FIG. 165.—Complete View of Kennedy's Two-Phase Motor

The following rules for designing such machines are given as good practice:[1]—Clearance (iron to iron) $\frac{1}{100}$th the diameter of the rotor. Flux densities: in air-gap, 30,000 lines per square inch; in stator teeth, 60,000 lines per square inch; in rotor teeth, 80,000 per square inch. Current density in rotor wires, 1100 to 1500 amperes per square inch. Peripheral speed, 6000 feet per minute. Ampere wires per foot in rotor, 300 for sizes up to 5 H.P. and 450 up to 100 H.P. These data and the fundamental formula $E = 4.4 \times \sim \times S \times N_p \times 10^{-8}$ (S and N_p being the number of turns and the number of lines per pole) give the data for calculation in C.G.S. units.

A diagram of an induction motor stator and rotor is shown in Fig. 166. The rotor carries copper rods in holes, and these are joined by a copper ring at each end, shown by the inner thick circle. The stator has oblong holes for winding in the exciting coils. One set of coils are shown dotted in, forming one pair of poles, the other set of coils would be similarly wound into the hole between, shown empty—that is, for a two-phase machine; for a three-phase machine the holes would be divided into six instead of four, and three sets of coils used.

Ampere wires per foot in stator means this, say, for a four-unit machine on 200 volts,

$$\frac{4000}{200} = 20 \text{ amperes the current,}$$

then the number of wires per foot of periphery would be $\frac{300}{20} = 15$ up to 5 H.P., and $\frac{450}{20} = 22.5$ up to 100 H.P. Say the four-unit machine had an armature 3 feet in circumference, then $3 \times 15 = 45$, the number of holes and wires in the rotor.

[1] Eboral in Society of Arts lectures.

A rule for the radius of the rotor is given where r is radius, and S speed in feet of periphery—

$$r = 100\sqrt{\frac{\text{H.P.}}{\text{S}}}.$$

The current density in the wires may be as high as 1000 per square inch in the stator.

Mr. Heylands proposes to overcome the difficulties arising from

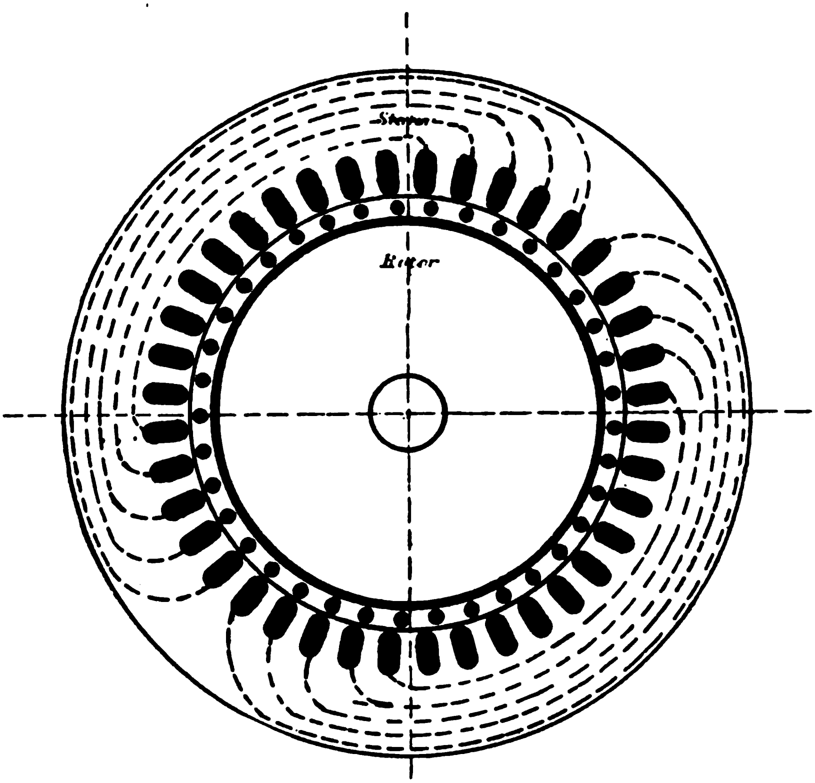


FIG. 166

self-induction and magnetic resistance in induction motors by feeding in current by brushes on the armature.

The idea may be gathered from the following statement and illustration copied from the inventor's description given in the *Electrician* of London.

The principle employed is as follows:—Let Fig. 167 represent a three-phase induction motor with a simple short-circuited armature —a so-called squirrel-cage armature. Let A be the stator or primary armature of the motor, and B the rotor or secondary short-circuited armature with copper bars distributed in holes or slots around the circumference, these bars being short-circuited at each end of the

armature by a ring K. Then, as is well-known, a three-phase alternating current generates a rotatory field in the stator A, which traverses equally both armatures (the stator A and the rotor B), and sets up a turning moment between the stator winding and the closed armature winding of the rotor.

The problem is to convey currents into the winding of the rotor, which is closed in itself, and to convey them in such a way that they have exactly the same direction and phase as the magnetising currents of the stator which they are to compensate.

The simplest way to do this is, as shown diagrammatically in Fig. 167, by three brushes *b b b* which are in contact with the end of the ring K of the armature, and whose position with regard to the stator is so adjusted that the currents led to the armature have exactly the same direction as the magnetising currents of the stator had. The pressure of these currents need only be very small (even if one assumes approximately the same number of turns on the stator and rotor), and they can be taken from a few turns of the stator.

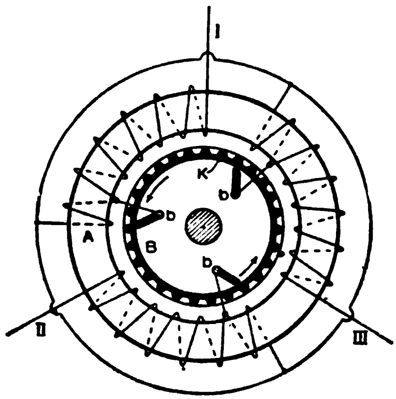


FIG. 167

Thus a conversion of the current takes place from high frequency (primary armature) into low frequency (secondary armature), and yet we have not employed for this a commutator in the ordinary sense of the term, but have accomplished the conversion, as is seen in the diagram, by a continuous ring. In general, the so-called squirrel-cage armature would not be used, for the currents under the brushes would be too great. For example, a wound armature could be closed by a ring whose resistance bears a certain relation to the resistance of the winding. This has not any great effect on the efficiency. In the first place, the losses in this ring need only be small, and in the second place, we can reduce the losses in the winding by making the slots deeper and putting some more copper on the armature. The increase in the magnetic leakage thus caused is not important, as the phase difference is avoided by the arrangement described.

The most remarkable thing about the motor is the commutation of the current by a commutator formed of a ring closed on itself. It is natural that such a commutator is not at all complicated, and works as simply and sparklessly as the usual slip rings on induction motors. A pertinent objection is that a part of the exciting current must be lost in the shunt which the ring

forms to the winding. This is correct, but by the arrangement described the exciting current is already so reduced that this loss is without importance.

In all induction motors the principle is the same. A primary current sets up a secondary current by magnetic induction, and the reaction between the induced secondary current and the magnetic flux causes rotation. A single-phase motor is just the same as a polyphase motor in principle, only it is like a single cylinder engine—it has dead points which it cannot get over without assistance. The two-phase motor is like an engine with two cylinders and cranks at right angles; there are no dead points, hence it starts itself. The three-phase motor resembles a three-cylinder engine with three cranks 120° apart—also starts easily.

The single-phase motor requires a separate starting winding on the field-magnet, or stator, or primary, as it is variously called. And by means of a resistance put in circuit, and connecting it in at the start, the current is divided into two circuits for the time being, and there is a difference of phase in the two circuits caused by the induction in the one and the resistance in the other, which starts the motor; but the starting-power even then is weak, for the phase difference is not great, and the pull small on the armature. However, in small powers they form serviceable motors, and once started give a good efficiency. The only fault I have found in using them is that they are worked at too high a magnetic flux density in most cases, thus causing heating to a great extent in the iron of the stator and rotor.

It is surprising how little has been done with the synchronous alternating motor in large towns like Leeds, where alternating currents have been so long in use and current available cheap for motors. There is also another type of motor suitable for alternating currents, single-phase, which is worthy of further development for small powers. Elihu Thomson's form of this motor is shown in Fig. 168. It consists of a laminated horse-shoe magnet, with an ordinary ring or drum armature, and a commutator with brush short-circuited. On sending an alternating current through the coil on the magnet, currents are induced in the armature winding, which are partially directed by the brush circuit into a path where they cause

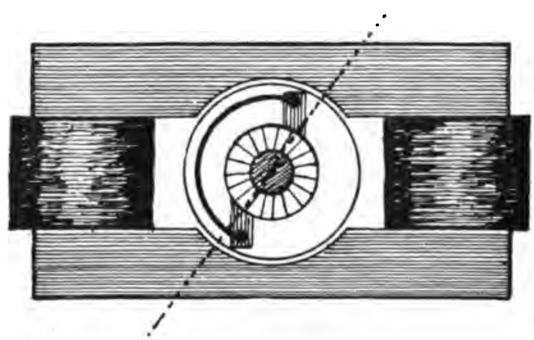


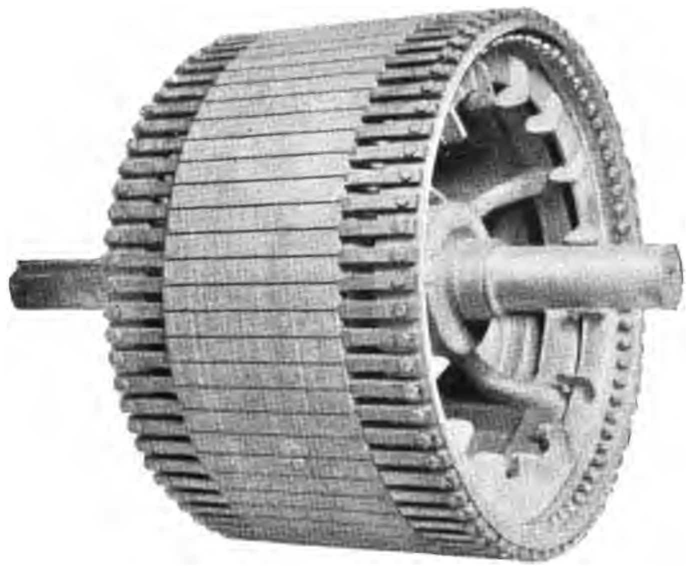
FIG. 168.—Elihu Thomson's Single-Phase Motor

a turning of the armature. Without the brushes the currents would circulate equally on each side of the armature. There would be equilibrium when at rest, as shown and explained by my disc experiments, Figs. 159 and 163; but if we could spin the armature round we would carry the induced currents round into positions where the magnetic field would act upon them effectively, and the speed would go up and the rotation go on. In Thomson's motor the opposing current slips across from brush to brush, and so allows the acting currents to start the motor; the brush to brush current upsets the equilibrium, hence the starting effect. The same disturbance can be caused by other means if we take a disc, as in Fig. 169, balanced on a point, and place it over an alternating magnet; no movement will occur—there is equilibrium. But put in a strip of copper to one side of the pole to cover a little bit of it, and rotation will at once commence; why? simply because the induced currents in the disc are not now concentric and equal all round the pole: the copper strip takes up a portion of the field to one side, and shifts the induced current in the disc, thus causing a pull to one side.

The author has devised a motor for small powers, like the Elihu Thomson machine, with a pair of brushes on the armature. The stator is like that shown in Fig. 166, four polar. The rotor is a slot wound armature, one bar in each slot; these are coupled in series as a gramme or drum or barrel winding. There is no commutator, the brushes being applied direct to the copper bars to start the machine, and switched off when full speed is attained; with the addition of the brushes the machine is like all other induction motors in action and in appearance. The illustration (Plate III.) shows the general design of the parts of the standard Westinghouse motors on the Tesla system.

Fig. 169

The chief drawback to all alternating motors yet devised is that they cannot be regulated in speed: the synchronous motor must go at one steady speed; the induction motor must go at speeds near synchronism for economy, and cannot be regulated to ¾, ½, or ¼ speed, like continuous current motors.



Squirrel Cage Rotor of Tesla Induction Alternating Current Motor, showing complete construction

Tesla Westinghouse Induction Motor Stator

CHAPTER VII

DIELECTRICS AND ELECTROLYSIS

1. Dielectrics

Static electrical science proves that bodies may be charged with two different kinds of charges of electricity, positive and negative.

Every substance has an equal quantity in or upon it, so that they are naturally neutral, the positive quantity neutralising the negative quantity.

By various appliances we can separate the two electricities in a body, and in doing so expend force and do work; but when they recombine the work is given back.

So that in the electric circuit the dynamo produces electrical pressure in pulling the two electricities apart, separating them in the machine by the power of the engine; they then press through the external circuit to rejoin again—for convenience we suppose they flow along in one direction only, from positive to negative. But the theory is that the negative electricity is thrown apart to the negative pole, and the positive electricity to the positive pole by the machine, whether a dynamo, a battery, an influence machine, or a frictional machine, and that the separated charges press or strain everything around to reunite again.

If a wire is led from pole to pole they reunite, producing an electric current; that is, the conditions allow them to recombine, a condition whereby electricity separated into positive and negative recombine through a substance called a conductor. If there is no conductor through which the separated electricities can combine again, or only a body through which they can combine less rapidly than they are separated, the two electricities strain the dielectric between them.

Referring to Fig. 170, a cell has two plates, zinc and copper, with two terminals T; so long as no conductor joins the terminals there is a negative charge on the zinc terminal and a positive charge on the copper terminal, pressing against the air with 1 volt pressure to rejoin.

If we join the two poles by a short copper wire, or good conductor, the electricities will recombine as fast as they are separated, and no strain is set up.

If we have plenty of power and no resistance in the circuit, the

electricities would be separated and recombined in great quantity. The amount separated and recombined is limited by the resistance of the circuit.

If instead of a wire joining the poles we fix large plates to them and put them near together, attach one pole to one of the plates and the other pole to the other plate, the plates will be charged by the opposite separated electricity. On first making contact a current will flow along the connecting wires into the plates, first rapidly, then more feebly, until they are charged.

The amount that will flow in will depend on the area of the plates, also on their distance apart, and upon what substance is between them. If the substance is a poor insulator the current will not absolutely stop, for some of the separated electricities will go on slowly passing through by "conduction."

Now the fact that the quantity of electricity charged on the

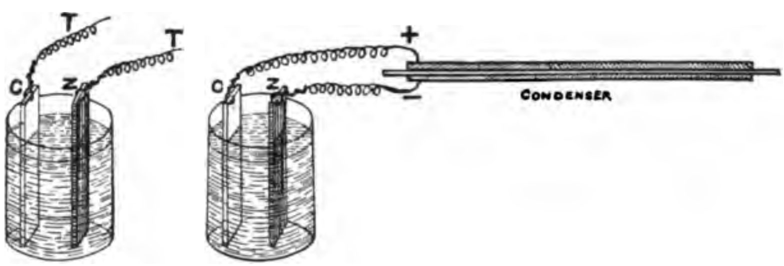


FIG. 170

plates depends upon their superficial area and on the nature of the substance separating them, shows that the electricities have effects in the substances separating them from recombining.

Any substance which is placed between two conductors, each charged with electricity of opposite kind, is called a "dielectric," and is acted upon by the opposite electric charges by "induction."

A perfect dielectric is acted upon by induction only, and does not permit conduction.

When the two poles of a generator are so separated, and no recombination can take place, then no separation can go on after the plates are charged. The separation of the electricities cannot be kept up without an equal amount of recombination. We talk of charging the plates, but in reality the charge is the strain in the dielectric. The electricity which flows into the plates in some way or other is converted into strain, like bending a spring; and if the strain is made great enough we find the dielectric is pierced or broken down, just as we break a spring by overstraining it.

Force in Dielectric

Fig. 171 illustrates an experiment which proves the force is stored in the dielectric.

Instead of two plates and a dielectric between them, we use a Leyden jar with movable coatings.

The coatings may be taken off as shown, touched together and otherwise tested, and show no charge, although the jar has just been fully charged; but the glass jar will show a charge still there, and on putting the coatings again in place the usual discharge takes place.

FIG. 171

There is no doubt that the air or other materials in contact with the poles of a generator or in contact with wires carrying electricity is strained by this inductive effect. All insulators are inductively acted upon by electrical accumulations of charge on their surfaces. The amount of electricity imparted to the different dielectrics to produce the same amount of strain is different with each different dielectric.

For instance, if two condensers (Fig. 172) are made up of two metal plates in every respect the same, but with air between the one pair and mica between the other pair, it will take about six times more electricity to charge the condenser with the mica dielectric than it does to charge the one with air as the dielectric to the same potential or pressure, the capacity being six times greater.

Therefore, if we wish to make an apparatus with the highest possible capacity for taking up a quantity of electricity to raise a high strain, we select the dielectric with the highest capacity to come between the poles or plates to be charged.

TABLE X.

Table of Capacities

Air	1
Glass	3 to 3.25
Ebonite	2.28
Gutta-percha	2.46
Paraffin wax	1.99
Shellac (solid)	2.75
Sulphur	2.58
Vulcanised rubber	2.7
Brown rubber	2.12
Resin	2.48

Air is taken as the standard of capacity. In electrical installation work capacity is of importance, as the materials of lowest capacity are used in insulators on cables and wire.

Capacity interferes with the efficient working of submarine and subterranean wires and cables, limiting the speed of working. It limits the telephone circuits also, and also interferes in alternating current work.

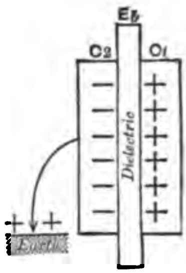


FIG. 172

Faraday predicted that capacity would interfere in the working of cables in earth or water.

Electrical engineering cables and wires are generally specified to have an insulation resistance of so many megohms per mile. A megohm is one million ohms, but very rarely is the capacity specified.

Prof. Fleming Jenkins first suggested a test of capacity on a one-mile length of gutta-percha insulated cable by the following experiment:—

One mile of the cable is immersed in a tank of sea-water, both ends being left out and insulated. As in Fig. 173, one end of the copper core is connected through a small current ammeter G.

To a high-pressure battery *Z* C, or dynamo, terminal P is connected; the other terminal M is connected to the tank of water, so that the gutta-percha covering forms a dielectric between the copper and water, and it will become charged like a Leyden jar—the copper forming the inner coating, and the water the outer coating.

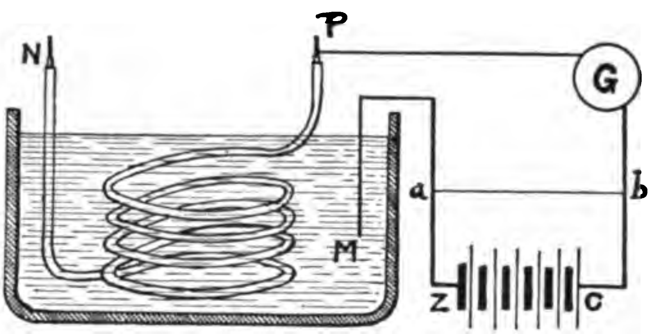


FIG. 173

On joining the generator on, the galvanometer G will indicate a sudden rush of current of great strength, gradually diminishing to zero, and upon disconnecting the generator and connecting a wire across *a b*, the cable discharges first strongly, and then gradually dying away.

To test the dielectric resistance in this way, the cable must be allowed to charge up until the current becomes steady. This steady current is that which passes through the "dielectric" or "insulation" by "conduction." The first rush of current is due to "capacity,"

and is absorbed by the dielectric, to be given up again upon discharge.

Cables for electrical work are thus tested, the battery being kept on for one minute at 500 volts, and marked according to their dielectric resistance in megohms — a resistance of very great importance in certain cases, and of little importance in others, as we shall see in practical works.

Oils are, as a class, good dielectrics; hence some high-pressure machinery is immersed in oil when at work.

When gutta-percha or rubber are pierced by a spark breaking through, an electric arc follows, and then a total breakdown follows; but a spark breaking through oil is often, if not always, extinguished and insulation restored.

FIG. 174

The wires used in engineering work are usually covered with rubber, jute, tape, and compounds of tar for water-proofing.

Here is a specification for a 300 megohm cable— that is, a cable whose dielectric resistances after twenty-four hours' immersion in water and tested with 500 volts pressure = 300,000,000 ohms per mile.

"Conductor of High Conductivity Copper, tinned and insulated with pure and vulcanised india-rubber, taped, and the whole vulcanised together." The object of the pure rubber next to the wire is to prevent the vulcanising from acting on the metal conductors. Minimum thickness of dielectric 41 mils., on a $^7/_{20}$ wire, insulation thickness.

Concentric and twin cables, in which the conductors lie close together, have capacity greater than single wires. Hence, in concentric cables the dielectric between the outer and inner wires has a large capacity; therefore a dielectric of low specific capacity is used. This is found in prepared paper, or jute; bitumen, oil, and tar being used to make the paper or jute non-hygroscopic. The paper has also an advantage mechanically when placed in a concentric cable, being flexible, strong, and yielding considerably without rupture.

Fig. 174 is a sectional view of Messrs. Glover's three-wire cable,

with three dielectric divisions between the three cables, and a circular dielectric between them and the outer lead tube; the lead is protected by iron wires.

Capacity is of no account in ordinary wiring of buildings, as the wires are too short to present any appreciable amount.

It tells in long mains carrying alternating currents; also in telephone circuits and, most of all, in submarine cables.

We need not go over all the elementary facts of statical induction; we may take it that from every charged body radiate lines of force connecting that charged body with surrounding bodies above, below, and on every side of it, and that so long as the charged body is insulated these lines of force remain, but the moment insulation fails they disappear. If the hand is brought near a highly-charged insulated body, the lines of force concentrate upon it as it approaches

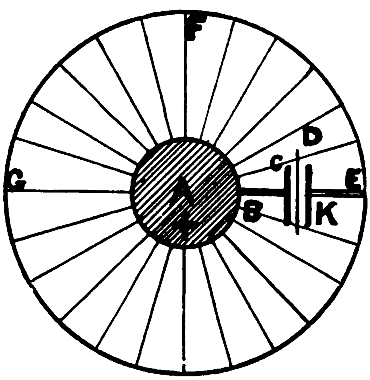


FIG. 175

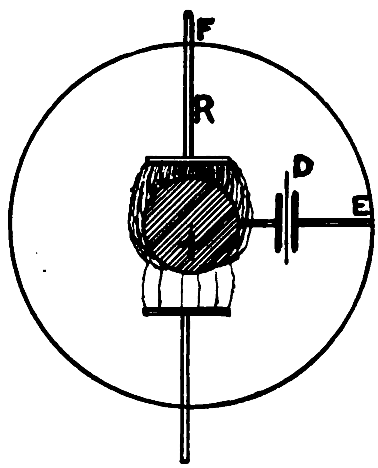


FIG. 176

until they become so dense that the dielectric breaks down and a spark results, the electricities recombining.

Take Fig. 175 as an insulated charged body inside of a circular room. A is the positive body, connected by B to electric source D, and the other pole of the source to E or the walls of the room. The radial lines are lines of electric force, in this case spread equally dense as they go out. There will be an equal charge on the outside of the ball and the inside of the room of opposite kinds of electricity.

Now if, as in Fig. 176, we connect a disc by a conductor to the wall at F, and bring it nearer to the insulated body, the lines will converge upon this second body, for the space between them has least resistance, and therefore the lines will disappear from other regions; until, when the two almost touch, the whole of the lines will be connecting the two bodies, and the strain very intense

between them, until it breaks down the dielectric and a spark occurs.

Not only do all the original lines converge upon the advancing earth-connected body, but as they approach the induction increases, thus separating more electricity at generator D; hence before rupture occurs the number of lines connecting the two are multiplied greatly. The strain and the tendency to spark depends on the number of lines of electric force between the bodies.

In fact, the force is in the space between the bodies, as it was in the glass between the coatings of the Leyden jar; and the strength of the force can be represented by the density of lines in any given space.

The lines may be considered as representing the charge in that respect.

When we charge any body we don't put anything into it or upon it, but we set up a field of force represented by radiating lines between it and all surrounding bodies, and all the attractions, repulsions, inductions, sparks, and other effects exhibited by the charged body are due to these lines of force in the space or dielectric between the charged bodies and other bodies.

All the tricky experiments made with pith balls, gold leaf electroscopes, bunches of hair, and proof planes, described in elementary books, are simply experiments made in a dielectric between two charged surfaces, as they are called; they should, properly speaking, be called polar surfaces, or poles. The two plates of a condenser or two coatings of a Leyden jar are similar to two poles of a magnet in effect.

Whatever be the theory as to the transmission of the electrical energy, the engineer is compelled to look upon the conductor as the carrier, to proportion it to the amount to be carried, to provide a good insulator between it and other bodies, and to avoid contact with any conductor under high pressure himself, and to keep others from contact therewith.

While the dielectric may be handled with impunity, the conductor cannot be so treated.

A dielectric subjected to rapidly alternating charges becomes heated, due to the rapid reversals of its polarity, thus showing that the material of the dielectric absorbs power, and requires energy to charge it in order to overcome internal resistance or friction. This is a source of loss in cables carrying rapidly alternating currents.

The capacity of a condenser depends upon the extent of the area of contact between the conductor and dielectric, so that to make condensers of large capacity it is usual to build up a series of plates of dielectric and metal, usually tinfoil.

The dielectric is usually of paper soaked in melted pure paraffin

wax. There are two kinds of paper used—finest "bank wove," and "butter skin" paper; the latter is perhaps the best.

The paper is cut to size and carefully dried; each sheet is drawn through a bath of melted wax, care being taken not to overheat it; two thicknesses of paper are taken and laid between each sheet of tinfoil and the next, piling them up to the desired amount.

Care must be taken to exclude all air bubbles. In laying on the tinfoil plates or sheets they are left projecting alternately at each end, so that they can be coupled into two bunches and to insulated terminals.

The farad is the unit of capacity. A farad is a capacity such that 1 volt charges it with 1 coloumb, that is, 1 coloumb on each conducting surface.

If A be the cross sectional area of the dielectric between the conductors, and the dielectric is air, and t the distance between them in centimetres, then F, the capacity in farads, is equal to—

$$\text{1st.}\quad F = \frac{A}{1.131 \times 10^{13} \times t},$$

if A and t are taken in inches, as they will be in Britain—

$$\text{2nd.}\quad F = \frac{A}{4.452 \times 10^{12} \times t}.$$

F is evidently rather a large quantity, as can be seen from above figures, for A would require to be a good many acres to contain one farad.

In practice we use the microfarad, one millionth of a farad, represented by M.

$$\text{Then } M = \frac{A}{4.452 \times 10^{6} \times t},$$

or

$$M = \frac{A}{4.452 \times 1{,}000{,}000 \times t},$$

so that with air as the dielectric, to get a capacity of 1 microfarad, with t equal to $\frac{1}{10}$th inch, the area of the dielectric would be equal to

$$A = 4.452 \times 10^{6} \times 0.1 =$$
$$4.452 \times 10^{5} =$$
$$4{,}452{,}000 \text{ square inches.}$$

If instead of air we used glass which had six times the capacity of air, then, if the glass had the same thickness, the area required would be one-sixth of the above.

Paraffined paper has about twice the capacity of air, and the thickness of two sheets when paraffined is about 0.04 inches; with these values a condenser can be calculated out to give any desired capacity, thus—

$$A = \frac{4.452 \times 10^{6} \times 0.04}{2}.$$

The capacity of concentric cables is calculated by a different

formulæ, using logarithms ; but as the materials used for the dielectric are mixed and variable, the capacity is best found by actual tests on a measured length.

Condensers are stores of energy like a wound-up spring in a clock, and although the store is not large even with large condensers and large pressures, yet they can produce powerful effects, for the current produced in discharging is immense while it lasts. Electrical energy is $= E\,C\,t$—that is, the pressure multiplied by the current multiplied by the time the current flows.

The time is exceedingly short in a condenser discharge and the current proportionally large, but so short is the time that little total energy is expended.

The work which the stored energy can do—

$$\text{Foot-lbs.} = \frac{F \times V^2}{2.712}, \text{ where } V^2 \text{ is volts.}$$

A 10 microfarad condenser on 250 volts calculated on this formulæ, $F = 0.00001 \times 62500 \div 2.712 = 0.2305$ foot-lbs. in each charge and discharge.

A cable of this capacity, and working at 250 volts, would take an idle current flowing out and in continually on an alternating current

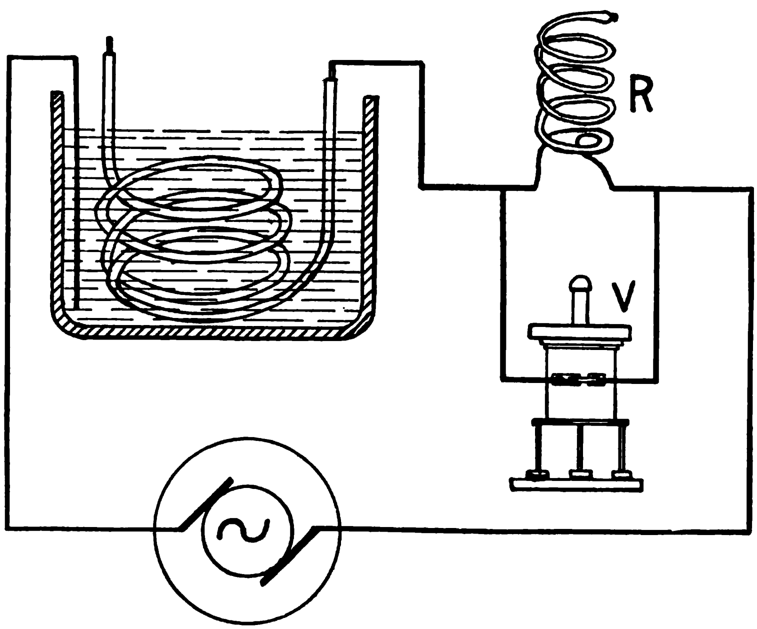


FIG. 177

circuit corresponding to this amount at each alternation of pressure. And in practice some of the energy is lost in the dielectrics used, as shown by the fact that they become sensibly hotter with alternating currents.

Referring back to Fig. 173, the capacity of cables can be practically measured by an arrangement as shown there, using a generator at Z C, which will give, say, 250 alternations per second with, say, 1000 volts pressure. G is an ammeter capable of reading accurately on high alternations.

The best arrangement for the purpose is to use a voltmeter across a resistance, as shown in Fig. 177. R is the non-inductive resistance of known value. V is a multicellular Kelvin voltmeter which reads amperes across the resistance R.

This arrangement will not give the real value of the current at any time during its rise and fall, but it will give, if we read the indications of the voltmeter, an indication of the energy reciprocating out and in the cable due to its capacity. Another method uses a transformer at R. This method will be described later.

2. Electrolysis

This important subject interests all electrical engineers working in the branches connected with electroplating, electrotyping, electrical reduction and refining of metals, the production of chemicals such as caustic soda, chlorine, potash chlorate, phosphorus, carbides of lime, carborundum, ozone, hydrogen, oxygen, aluminium, and other elements.

Electrical energy is applied in two distinct methods by the engineer for industrial purposes.

First, by passing electrical currents through fluids, solutions of metallic salts, or fused salts, whereby the chemical compounds are split up into metals or other compounds.

Second, by applying the electrical energy to solid substances, thereby raising them to intense temperatures while under the action of the current, the combined action of great heat and great current effecting the work to be done chemically.

A third method may be mentioned, namely, the combination and decomposition of elements by passing electrical discharges, sparks, or brushes through gases.

The electrolytic cell simply contains a liquid and two terminal conductors in the form of plates usually immersed therein, and capable of being connected up to a circuit supplying electrical energy.

Sometimes there are two liquids used, separated by a diaphragm or porous partition through which the current can pass.

Referring to Figs. 178 and 179, the simple electrolytic vat or cells, one with a partition of porous material to keep two different liquids apart.

The conducting plates are called by distinctive names—the one attached to the +, positive supply, is called the anode; the current is supposed to enter the liquid from this plate, the anode.

The current flows through the liquid which is called the electrolyte, and enters the other plate, called the cathode.

All solutions are not electrolytes, but those which are electrolytes are acted upon by the electrical energy passing between the anode

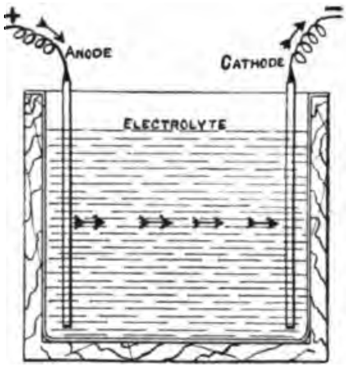


FIG. 178

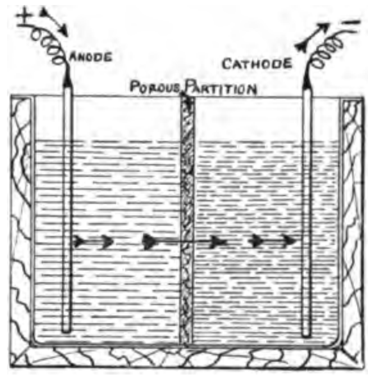


FIG. 179

and cathode, the effect being a decomposition of the compounds in the solution, and the liberation of some elements.

If the solution is common salt, the chlorine and sodium are separated; if the solution is sulphate of copper, copper and sulphuric acid are separated; if the solution is acid and water, their oxygen gas and hydrogen gas are separated.

Sometimes the object of the separation is to deposit one of the elements upon a plate or other object, either as a thin covering of superior metal, as in electroplating, or to deposit a bulk of metal, or to procure gases, or to procure chemical compounds—the process is much the same.

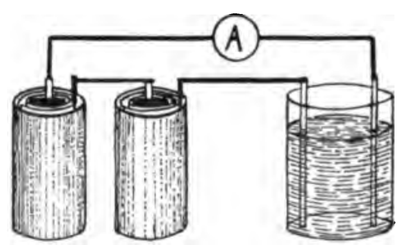


FIG. 180

Referring to Fig. 180, if the plates are of platinum, so that they are not acted upon by the solution, and the solution is of sulphuric acid and water, on connecting up the plates to a couple of large cells gas will immediately begin to pour from the surface of the plate, and continue to do so as long as the current flows.

This is an example of two elements being produced in one cell; the gases may be collected and utilised.

If the solution is now changed to copper sulphate, and the

current passed between the platinum plates, the one plate, the cathode, will become first coated with copper and then give off hydrogen gas, while the anode will give off oxygen gas, just as happened before, only the copper appearing on the cathode being the different effect. As soon as the copper in the sulphate is deposited on the cathode the solution becomes simply a sulphuric acid solution, which we had at first.

But if we take another sulphate of copper solution and make the anode of copper, and turn on the current, we will find that copper goes on depositing on the cathode. No gas appears there, nor does gas appear at the anode, and if the current is continued long enough the anode will be seen to grow smaller and the cathode larger. In fact, the copper of the anode is dissolved and maintains the strength of the solution, so that copper is constantly deposited at the cathode.

In this case we have a metal transferred from the anode to the cathode: this is the process in electroplating and electrotyping.

It is also the process used for the electrical refining of metals; the raw impure metal is made to serve as the anode. It is there gradually dissolved and deposited in a more or less pure state on the cathode, the impurities dropping to the bottom of the cell.

In this process nothing is liberated, the metal of the anode is simply carried across to the cathode by the current.

In this way we can use a silver anode and cover a Britannia metal teapot with a thin coating, or we could take a mould of a saucepan, and using a bar of copper for an anode, deposit copper on the mould until it was thick enough to make a useful saucepan, or using a round bar of wood deposit a copper tube thereon.

Now, if we take a common salt solution and use the platinum plates, we shall decompose the solution; but the result will be—chlorine, a gas at the anode, and hydrogen gas at the cathode. Common salt is sodium and chlorine combined. The question is—What has become of the sodium?

If we tested the solution we would find that it had become alkaline; in fact, the sodium had parted from the chlorine and combined with the oxygen of the water to form caustic soda in solution.

In this experiment we have first separated two elements, chlorine and sodium. The first we can collect, but sodium burns in water; if a piece is dropped on to water it takes fire, combining with the oxygen. Immediately the sodium is liberated at the cathode it is seized by the water, combining with the oxygen and liberating the hydrogen. Here we have first an electrolyte action, followed by a chemical action.

If sodium sulphate is used as the solution, the result of the electrolysis will be a liberation of oxygen at the anode and hydrogen

at the cathode, as if only water was decomposed. But on examining the liquid we would find soda at the cathode as well as hydrogen, also sulphuric acid at the anode.

In this case four products are the result. First, the sodium metal is freed at the cathode: this combines with the water, forming soda and hydrogen. $H_2SO_4Na_2$ is the formulæ for sodium sulphate.

SO_4 is liberated first at the anode; this also combines with the water, forming sulphuric acid with the hydrogen, and liberating oxygen.

This electrolysis should be effected in a cell with a porous partition, to prevent the acid formed at the anode from recombining with the soda formed at the cathode (Fig. 179).

In order to explain these effects of the two metal poles in a solution, the theory of Grotthus is usually put forward. According to this theory, the molecules are polarised in the solution. The molecules are composed of positive and negative atoms, so that when they come between the two plates of different poles, the negative atoms turn towards the positive plate and the positive atoms towards the negative plate, ranging themselves in chains. Fig. 181 shows this action in diagram: the top row of egg-shaped figures represents molecules arranged anyhow before the current is turned on. The second row shows the molecules immediately the current starts, all arranged in polar order. The third row shows the combination and decompositions going on.

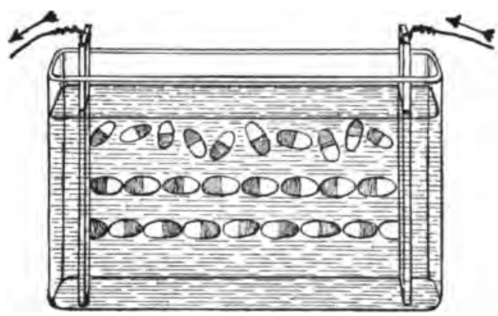


FIG. 181

We will suppose the electrolyte is water and acid sulphuric; the black ends are oxygen, the white ends hydrogen.

The atoms at the ends of the chain would be separated from the other atom in the molecule immediately it came in contact with the electrically active plates, the hydrogen being pulled apart at the cathode and the oxygen at the anode; and then an interchange of partners goes on along the whole chain, as in the third line.

The elements are divided into positive and negative elements, oxygen and hydrogen; for example, chlorine and zinc, carbon and oxygen combine, the one being positive and the other negative.

Thus we have compounds formed called sulphates, oxides,

and chlorides, by the combination of sulphur, oxygen, or chlorine with the metals, giving up energy.

The energy may reside in only the one class of elements, say the positive elements, the metals hydrogen and suchlike, in which case the negative elements are mere pieces of exchange for energy. For instance, zinc gives up so much energy in exchange for so much chlorine.

And, *vice versâ*, we must give back so much energy to the zinc if we wish to get the chlorine back again, and the zinc as zinc again.

The amount of any element deposited or freed by a current has been ascertained with some accuracy.

A table is here given showing the quantities of various substances or elements delivered per ampere-hour at the cathode.

TABLE XI.

Electro-Chemical Equivalents

Element.	Symbol.	Valency.	Chemical Equivalent.	Lbs. per 1000 Ampere Hours.	Ampere Hours per lb.
Electro-positive—					
Copper (cuprous) .	Cu	1	63.0	5.192	192.6
Hydrogen. . .	H	1	1.0	0.08242	12130
Mercury (mercurous)	Hg	1	199.8	16.47	60.73
Potassium . . .	K	1	39.04	3.218	310.8
Silver . . .	Ag	1	107.66	8.873	112.7
Sodium . . .	Na	1	22.99	1.895	527.8
Copper (cupric) . .	Cu	2	31.5	2.596	385.2
Iron (ferrous) . .	Fe	2	27.95	2.304	434.1
Lead	Pb	2	103.2	8.506	117.6
Magnesium . .	Mg	2	11.97	0.9866	101.0
Mercury (mercuric) .	Hg	2	99.9	8.234	121.5
Nickel . . .	Ni	2	29.3	2.415	414.1
Tin (stannous) . .	Sr	2	58.9	4.854	206.0
Zinc	Zn	2	32.45	2.674	373.9
Aluminium . .	Al	3	9.1	0.7500	1333.0
Gold	Au	3	65.4	5.391	185.6
Iron (ferric) . .	Fe	3	18.63	1.536	651.2
Tin (stannic) . .	Sr	4	29.45	2.427	412.0
Electro-negative—					
Bromine . . .	Br	1	79.75	6.573	152.1
Chlorine . . .	Cl	1	35.37	2.915	343.0
Iodine . . .	I	1	126.53	10.43	95.89
Oxygen . . .	O	2	7.98	0.6577	1520.0
Nitrogen . . .	N	3	4.67	0.3849	2589.0

The electro-motive force required varies according to construction of cells, resistance of liquids, and connections.

In practice these quantities are not obtained owing to losses and impurities, and to some energy going into gases produced.

Counter E.M.F.

The two elements in a solution forming an electrolyte are called ions.

Faraday's laws of electrolysis are:—

1. No elementary substance can be an electrolyte. It must be composed of positive and negative ions.

2. Electrolysis occurs in liquids only.

3. During electrolysis the components of the electrolyte are resolved into two groups, one takes a definite direction towards one electrode, the other group takes a course towards the other electrode.

4. The amount of electrolysis depends upon the current strength.

Miller, the famous chemist held that—

Those bodies only are electrolytes which are composed of a conductor and a non-conductor.

Current passes through an electrolyte without electrolysing it if the pressure is below that required to separate the two ions.

Thus in the case of water in an acid solution current will pass from anode to cathode with one Daniell cell, but no gases will be formed; it has only one volt pressure, and water takes 1.5 volt to break it up. If we put on two cells the gases will be formed and given off at once.

Let us set up our ammeter A in a circuit with two large batteries in series (Fig. 180), and a cell containing sulphuric acid and water solution and two platinum plates, with a resistance to regulate the current; say we pass half an ampere for a few minutes, then disconnect the battery and join the ends of the circuit together, the ammeter will indicate a reverse current, showing it has become charged.

This fact is of importance, for it proves that the gases exert a counter force against the working pressure; that is, as soon as they are formed at the plates they have a counter electro-motive force.

This is the case where ions are liberated. They oppose a counter force, so that in every case there is a certain pressure required for the purpose of overcoming the counter force of every electrolyte, a minimum pressure below which electrolysis cannot take place in a decomposition cell.

There are two kinds of electrolytic cells—decomposition cells, like the foregoing—in which ions are liberated and counter force set up.

In the case of other cells, such as the copper sulphate and copper plates cell, in which no ions are liberated, there is no counter force, for the energy expended in separating the copper from the sulphuric acid at the cathode is given up again at the anode by the combination of the copper with the sulphuric acid.

In these cases the pressure is employed in overcoming the resistance of the cell only, plus a small counter force due to the positive plate and negative plate being in solutions of different strengths, for it is always stronger at the anode than at the cathode.

Electrolytic cells are therefore of two kinds: decomposition cells, in which ions or elements are separated and liberated, and transfer cells, in which there is merely a transfer of metal or an ion from the anode to the cathode.

Experiments in electrolysis are easily made and very instructive. The voltmeter reading to 10 or 12 volts must be continually used, also the ammeter reading to 5 amperes, as before described in Chap. II.

The student should be provided with these instruments:—

Voltmeter to 10 volts.

Ammeter to 5 amperes.

Current supply, 10 volts and 5 amperes.

Resistances variable to vary current.

A set of small test tubes.

Simple qualitative chemical tests for acids, alkalies, chlorates, chlorides, sulphates, sulphides, and other ions.

A balance with weights to weigh metals.

And the following solutions for electrolysis:—

1. Sulphuric acid and water about 1150 sp. g.
2. A solution of copper sulphate made as follows: saturated solution of copper sulphate in soft water, 1.5 pints; add to this half-a-pint of sulphuric acid solution, sp. g. 1080.
3. A solution of common salt saturated.
4. A solution sodium sulphate.
5. A solution of ammonia sulphite.
6. A solution of potass chloride.
7. Two glass jars to hold the solutions and electrodes when making experiments; two porous pots.
8. Electrodes: two small platinum foil electrodes, two lead, two copper, two carbon.

The platinum foils may be each half an inch by two inches. As the platinum is very expensive, and is used only for water decomposition, it may be left out and lead used instead for the water experiments, in which case the student must take into account the fact that a higher pressure will be required to decompose water with lead electrodes, because the anode becomes oxidised to peroxide and the cathode covered with hydrogen. These two oppose a counter force to the battery or other acting pressure equal to over 2 volts, and to get abundance of gas two or three cells in series is required.

Platinum is not chemically acted upon, hence it has no counter

force itself, the counter force being due to oxygen on the anode and hydrogen on the cathode, about 1.5 volt.

With these apparatus the student should get a fair insight into the science of electrolysis by performing experiments, noting the current, and pressure, and time during the experiment.

First, take a soda-water bottle, as in Fig. 182, with two lead electrodes, strips about $1\frac{1}{2}$ inch × $\frac{3}{8}$ and about $\frac{1}{16}$ inch thick, soldered to two wires; pass the wires through a cork, preferably of rubber; put a small tube of glass through centre of cork, as shown; fill the bottle with sulphuric acid solution in water, sp. g. 1050 or 1100; then invert the bottle so that the end of the glass tube dips into a vessel of acid solution or water. This vessel may be a jam-pot or glass preserve jar deep enough to hold the contents of the soda-water bottle and narrow enough at the mouth to support the bottle. Connect the wires to the battery, taking enough cells to give 2 amperes current cells in series.

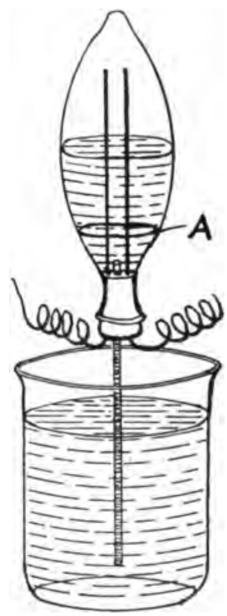


FIG. 182

Gas will immediately arise from both poles and displace the acid solution, which will pass through the tube to the jar, and the mixed gases collect in the bottle. As soon as the solution reaches the level of the electrodes the decomposition may stop by removing the battery connections; then remove the bottle, pull out the cork, and fire the mixture of gas by thrusting a lighted taper into the mouth of the bottle; it will explode violently, so that it is well to wrap a towel or a woollen duster round the bottle in case it should burst. This will prevent glass flying and doing possible damage. It is also better to keep the mouth of the bottle pointed away from any person.

This experiment will show that the constituent parts of water have, when separated, a considerable amount of energy, which they give up again at the moment of combining. Next take a large test tube or a burette (Fig. 183), to fit the same cork with the electrodes and tube, or take the bottle again for another test, this time to find how much gas is liberated per ampere-hour or minute. First mark the bottle at the level A, weigh the empty bottle, and note the weight; then fill the bottle with water up to the mark, weigh it again — the difference will be the weight of water, and from this weight we can find the cubic inches of the contents of the bottle up to the mark. Suppose bottle weighs 0.25 lb., and with water weighs 1 lb., then $1 - 0.25 = 0.75$. A cubic

inch of water weighs 0.0361 lb., hence $\frac{0.75}{0.0361} = 20.8$ cubic inches Now fill the bottle chock-full of electrolyte, sulphuric acid solution again. Invert the bottle with tube into the jar, and turn on the battery current to give exactly 1 ampere. Here note that if lead electrodes are used always to make the same plate anode. In the first experiment this plate will be seen to change in colour. It will be oxidised, and the colour chocolate brown. If it were used now as the cathode this oxide would absorb hydrogen, and the anode would absorb oxygen for a short time until the one lost its oxide and the other became oxidised.

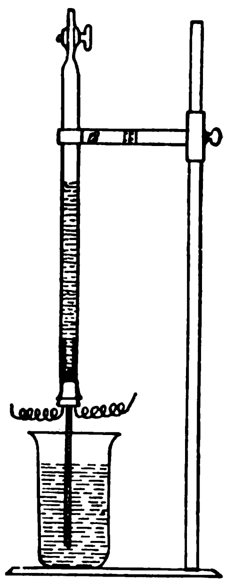


Fig. 183

The decomposition is allowed to go on until the liquid in the bottle falls to the marked point. Immediately this is reached the time must be taken carefully and the action stopped.

It will thus be found how long it takes a current of 1 ampere to produce 20.8 cubic inches of mixed hydrogen and oxygen gases, not exactly accurately, but near enough to prove the rate practically.

If the two electrodes are immersed in an open glass full of solution of acid, say to a small depth of half an inch, and all the 10 or 12 volts at disposal turned on, the peculiar smell of ozone will be at once detected in the gases given off. Ozone is a condensed form of oxygen, and is formed when the electrodes are very small and the pressure great. If the proper tests were made it would also be found that the hydrogen given off under these conditions is not pure, but contains peroxide of hydrogen.

The excess of pressure at the small electrode causes this condensation of the oxygen and the combination of the hydrogen.

To obtain pure oxygen and hydrogen it is necessary to have large electrodes, and work with a pressure not much over 2.2 volts.

It will be seen that the pressure is of importance in obtaining certain results, hence the size of electrodes must be regulated to bring the pressure to the value desired with the current we intend to use. If we intend to use only 1 ampere, and it requires 6 volts to give off oxygen with considerable ozone, we must reduce the electrodes till the current is 1 ampere and pressure 6 volts.

If we want pure oxygen we must reduce the pressure to about 2.2 or 2.4, and increase the anode and cathode till the current is what we desire.

Electrical energy can be had as low as 2d. per unit of 1000 watt-hours.

From the Table VIII. of Electro-chemical Equivalents we find that 0.0824 lb. of hydrogen is liberated per 1000 ampere-hours, and 0.657 lb. of oxygen, or by calculation, 26.5 cubic inches of hydrogen and 13.25 cubic inches of oxygen per ampere hour.

Now, if it took 2.5 volts to effect the separation, 400 amperes for one hour would give 1000 watt-hours, and we would get 400 ampere-hours for the price of 2d.; hence $400 \times 25.6 = 6$ cubic feet nearly of hydrogen, and $400 \times 13.25 = 3$ cubic feet of oxygen for 2d. in energy

There are several difficulties in the practical manufacture of these gases by electrolysis, but much progress is being made in overcoming them.

We may now make a test with the copper solution and copper plates.

First find the amount of copper deposited by 1 ampere in an hour. Take two very thin copper plates with terminal wires; clean them by dipping in acid solution and washing, dry thoroughly, and varnish one side carefully with paraffin wax, slightly heating them; weigh them separately carefully, and note the weights. Now hang the plates in a vessel in which they can be hung vertically parallel with each other, and about 2 inches apart. The amount of surface immersed should be 3 inches by 2 inches, so that the plates may be $3\frac{1}{2}$ by 2.

Put the plates into the empty vessel first, then make up all connections to battery and through an ammeter, and regulating resistance. When all is ready pour in the copper solution and quickly adjust the current to 1 ampere, and keep it steadily at that by adjusting the resistance, if necessary, for one hour. At end of this time stop the current, remove the plates, wash them in running water, dry them, and weigh them again. In this way we find how much one plate has gained and the other lost with 1 ampere in one hour. The table gives 2.59 lbs. as the equivalent for 1000 ampere-hours, so that the amount transferred should be

$$\frac{2.59}{1000} = 0.00259 \text{ lb.}$$

—a very thin coat.

If fine balance-weighing is not available, it is better to continue the deposit for 5 ampere-hours. The quantity will then be

$$\frac{2.59}{200}.$$

One cell is sufficient for this test, but it should be large—one of the large Silvertown cells—so that the P.D. will remain constant on the plates.

The deposit will be found soft, tough, and fine in texture.

Influence of Distance

In another experiment take a long containing vessel and place the plates a long way apart—8 or 9 incles, or even 1 foot—and pile on the cells of the battery until the 1 ampere current is obtained again, and let the current flow for two or three hours. Fig. 184 shows this vessel with two plates in the solution. Let the plates be immersed about same as before. A test with the voltmeter will show that the P.D. is much higher than before, because the long distance through the liquid requires higher pressure to force the 1 ampere through.

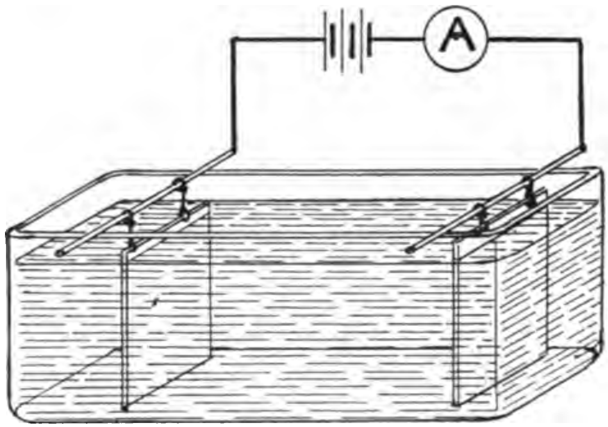


Fig. 184.—Hard Deposits

The resulting metal deposited will be found to be very hard compared with the first deposit, showing that the pressure affects the quality of the deposited metal.

One ampere per 6 square inches of cathode is about the greatest current to be used in electro-deposity copper to obtain a good sound metal.

And the anode and cathode should be near enough to work at a low pressure, but not too near; for if placed close together the deposit will be uneven.

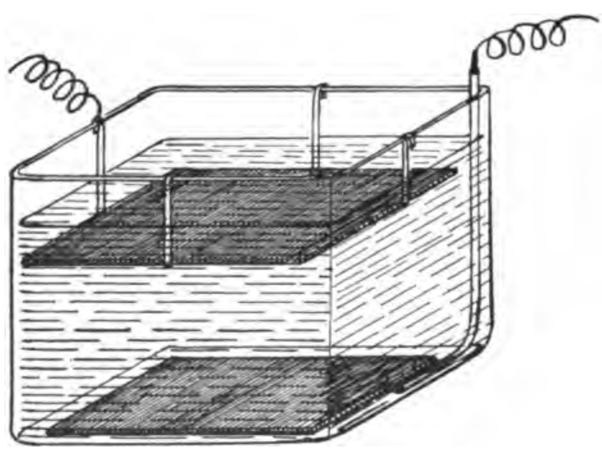


Fig. 185.—Best Position for Electrodes

A flat smooth plate at each electrode works at that 1 ampere per 6 square inches rate at 2 inches apart very well; but if the cathode is of an irregular shape, the distance must be greater and the rate less. The rate may be as low as one-fourth of this—1 ampere to 24 square inches.

Another experiment, Fig. 185: Put one plate at the bottom of the

cell, connecting it by a short piece of gutta-percha-covered or shellac-varnished wire, and hang the other over it at about 3 inches apart; fill up with copper solution, and send a small current, say 0.25 ampere, through from one Daniell cell. In a short time the current will fall to a small value if the upper plate is made the cathode, for the simple reason that the solution in contact with the anode becomes heavily charged with copper and cannot rise, while the solution at the cathode loses copper and becomes lighter and does not sink; consequently, there being in a short time only acid solution in water against the cathode, the action stops, for a 1 volt cell cannot decompose an acid solution in water.

But if we reverse the connections, we find the action goes on perfectly, for the heavy copper solution from the anode falls at once to the bottom, while the lighter solution formed at the cathode floats up.

Hence, even the position of the electrodes must be studied.

Stirring the solution has the effect of keeping its strength equal at both electrodes.

If a copper bar is placed between the electrodes, but not touching, as in Fig. 186, it will be found to grow at one end and dissolve away at the other, because some current enters from the anode at the nearest end and leaves for the cathode by the other end; where the current enters the metal deposits, and where it leaves it carries metal with it.

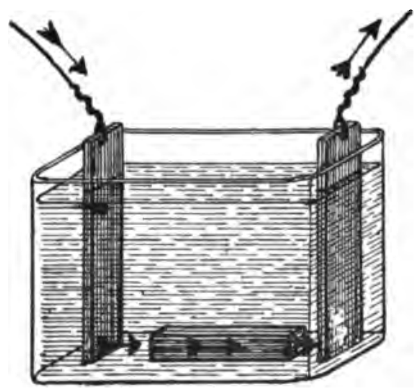


Fig. 186

Pure copper is usually obtained on deposit, even from impure copper plates in a sulphate solution. The impurities are usually carbon, tin, lead, sometimes gold and silver; but the sulphuric acid at the anode prefers the copper at a low electric pressure. If the pressure is great, some of these impurities will be dissolved and deposited by the current along with the copper. With the low pressures practically in use, these impurities form a dirty coating on the anode, which falls off and collects as mud at the bottom of the cell.

A chloride or nitrate solution would act on some of these impurities, and they would be deposited with the copper.

It does not at all follow that an electrically deposited plate of metal must be pure.

Alloys can be deposited, such as bronze and brass.

Method for Depositing Alloys

A brass depositing solution can be made of—

Water	10 parts
Cyanide of potass	1 part
Ammonium carb.	1 ,,

Put this solution in a beaker, heated to 150° Fahr., and place a cylinder of brass (a piece of brass tube, for instance) in the solution; connect it to the pole of two large cells, while the negative pole may be a rod of copper or brass, smaller in surface than the anode; the brass anode will dissolve and form the solution. The cathode may be put inside a porous pot. When brass deposits freely it is ready for work, using, of course, a brass anode.

Another brassing solution—

Water	2000 parts	
Copper chloride	10 ,,	saturated solution
Zinc sulphate	20 ,,	,,
Cyanide potass	24 ,,	,,
Carbonate potass . . .	160 ,,	,,

Mix the copper and zinc solutions with part of the potass carbonate, then add ammonia to dissolve any precipitate, then add the cyanide.

Two or three large cells are required 4 to 6 volts, with a large brass anode. Ammonia and cyanide require to be added if this solution is used for long, to keep it neutral and active.

Alloys may be deposited from anodes of the component metals; thus we may have copper for one anode and tin for another, or copper for one and tin and zinc for others, as in Fig. 187, wherein we have in this process separate cells or batteries which are used for the different component metals, and the currents are adjusted for each anode by the ammeters shown, A A A.

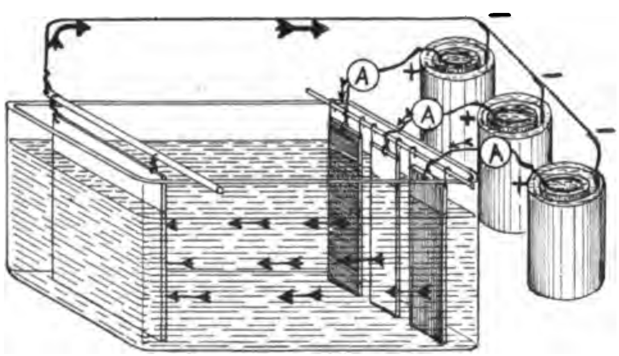


FIG. 187.—Depositing Alloys of Metals

The student may now electrolyse common salt and sulphate of soda, using a porous cell for the cathode and carbon rods for the anode and cathode. For these electric arc lamp rods do very well.

Ammonia sulphite is an interesting electrolyte; using an anode and cathode of carbon, a large anode outside of and a smaller cathode in a porous cell, pass two or three amperes through the saturated

solution. In time sulphur deposits at the anode, and after a considerable deposit a test will show that the sulphite is being converted into sulphate at the anode; while the sulphite in the cathode cell becomes strongly alkaline, ammonia being freed.

A decomposition of caustic potass (Fig. 188), with liberation of potassium, may be made by taking a small vessel with a layer of mercury at the bottom, connected by a covered wire; on the mercury a layer of caustic potass paste, and on this an iron or lead anode: a pressure of 10 or 12 volts is required. The potassium on being freed is absorbed by the mercury; otherwise, it would recombine with the water in the paste.

This principle of combining deposited metals with mercury to save them from being again combined is used for soda caustic production.

The presence of some compounds in a solution often alters the

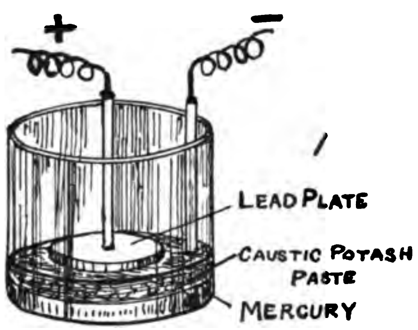


FIG. 188

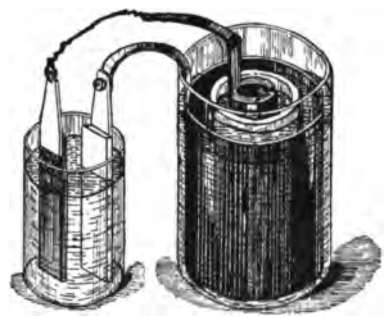


FIG. 189

effects; thus silver is deposited from an ordinary solution as a dead white rather dull surface. A little quantity of carbon bisulphide added to the solution brings the deposited silver out with a brilliant surface like a mirror.

Fig. 189 is an arrangement for an experiment in refining copper. An impure copper plate is used as the anode in a depositing cell; the cathode is a thin plate of copper. One Daniell cell is quite sufficient for the work. The current should not exceed 1 ampere per 6 square inches of anode; the plates should be same in size.

The experiment should last six or eight hours, and the quantity of sulphate of copper crystals used in the Daniell cell noted carefully as a measure of the work going on.

If the plates are cleaned in the cell, washed and dried, the difference in weight can be ascertained; and as the plates must be carefully weighed before the experiment commences, the gain and loss can be compared. It will be found that the loss at the anode is greater than the gain at the cathode. This is due to the impurities in the anode falling to the bottom of the cell, only copper going over to the cathode.

The anode should be brushed down in the cell before removing it, so that all loose impurities may be left in the cell.

The liquid in the cell can then be filtered, and the filtrate dried and weighed; this weight will go far to account for the greater loss at the anode.

In Fig. 190 we have a section of an apparatus for manufacturing oxygen and hydrogen on a large scale by electrolysis. The cell is

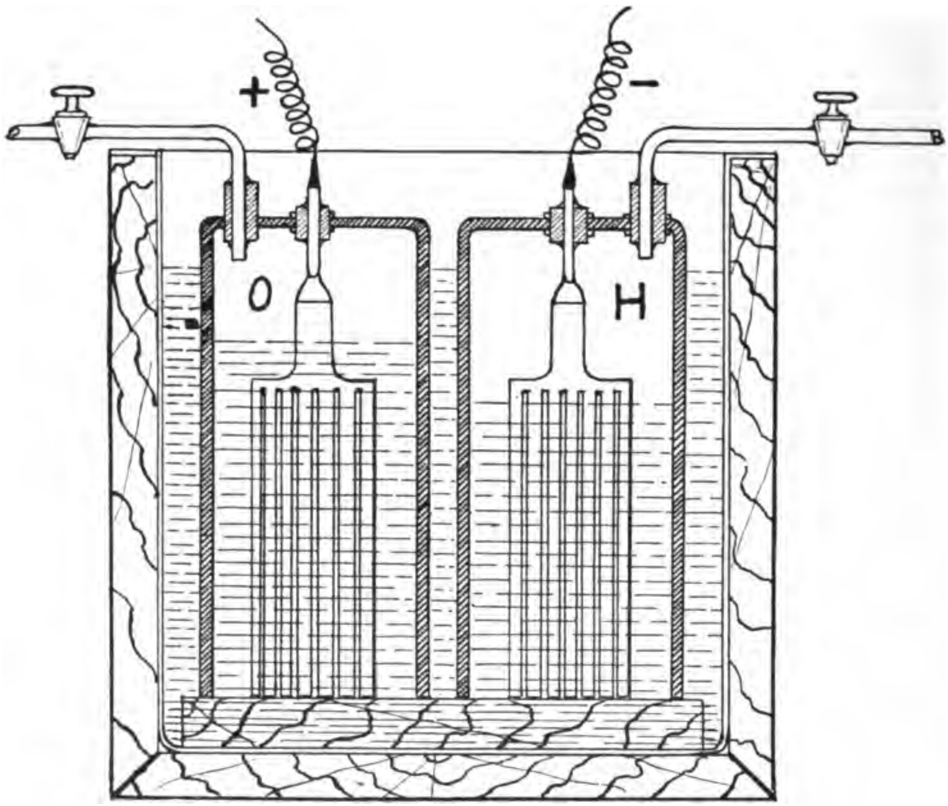


FIG. 190.—Production of Hydrogen and Oxygen by Electrolysis

of iron cased in wood, and contains a solution of caustic soda in water 15 per cent. strength.

Inverted bells of stoneware cover the electrodes. A bunch of sheets are used at each pole.

The gases are drawn off and stored by a pump compressing them into steel cylinders.

2.8 volts effect the decomposition of this solution economically.

The hydrogen thus obtained can be used in gas engines and other industrial work, while the oxygen is also in demand for many purposes, not the least important being its use in medical practice, in pneumonia and bronchial diseases.

There is likely to be a field of usefulness also for ozone and hydrogen peroxide produced by electrolysis.

Both of these substances have valuable properties. Ozone especially may be useful in purifying the air in large buildings, hospital wards, and other places, where free access to a pure atmosphere is not possible.

In all decomposition cells a charged state will be immediately observed after stopping the operations. That is easily found by immediately coupling the poles of the cell to the ammeter through about half an ohm resistance; a reverse current will be given back, the strength and duration of which differs with different electrodes and electrolytes.

In decomposing the sodium sulphate by lead electrodes, a back E.M.F. of 2.6 volts or so is found, and this is maintained for some time, for the anode becomes coated with lead oxides and the cathode surrounded by alkaline soda solution and hydrogen; these then act as batteries, the oxygen on the anode combines with hydrogen in the solution, and the alkaline solution at the cathode combines with the hydrogen on its surface.

There is also the effect of the same metal in two different liquids, for after the decomposition the anode liquid is acidulous and the cathode liquid alkaline, hence a current is set up due to that difference.

A copper and zinc plate in sulphuric acid soon ceases to give current, for the hydrogen liberated at the copper plate covers it, and being as positive as the zinc, there is very small E.M.F. between them.

For this reason, in all primary batteries of any practical service we must surround the negative plate with some chemical which will combine with the hydrogen, and keep the plate clean and free from the gas.

Daniell's cell is a very good example. In this cell the copper plate is in a solution of copper sulphate, hence the hydrogen is arrested, combines with the sulphuric acid in the sulphate, forming sulphuric acid and depositing clean pure copper on the negative plate, and therefore the current is constant so long as crystals of copper sulphate are supplied to the negative plate.

In Grove's cell the negative plate is platinum, surrounded by nitric acid, for arresting the hydrogen. Bunsen's cell is the same, using carbon instead of platinum for the plate.

Bichromate cells use bichromate of potass and a carbon plate. In this cell the zinc and carbon may be in the same liquid, as the bichromate does not act injuriously on the zinc.

In the Bunsen, Grove, and Daniell, the zinc and the negative electrode must be in separate liquids. The nitric acid would imme-

diately dissolve the zinc, and in Daniell's cell the copper sulphate would deposit copper on the zinc.

The large low-resistance Silvertown cell is a great improvement on the Bunsen as ordinarily made. The Bunsen cell, worked with nitric acid, is very "messy," and gives off dangerous nitrous fumes.

The Silvertown cell uses a bichromate of lime solution, or some such compound, which gives off no fumes and has a vast capacity for absorbing hydrogen. Bichromate of soda, gradually added to well-stirred sulphuric acid until it forms a pasty mass, makes a good solution for the negative plate.

The Leclanche cell uses manganese binoxide round a carbon plate.

The Leclanche cell is too well known to require description, but several improved forms are so useful that they might be referred to here.

The ordinary Leclanche cell has a high internal resistance, and the manganese does not absorb the hydrogen for any long time. It

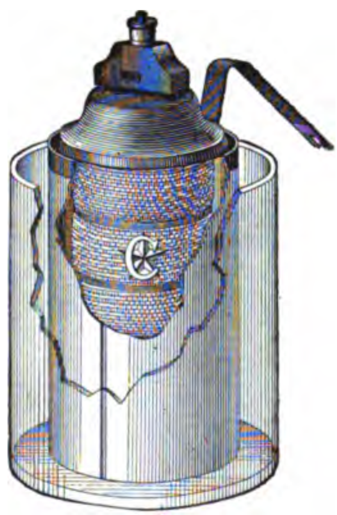


FIG. 191.—Le Carbone Company's "Z" Sack Cell

FIG. 192.—Large Size Sack Cell

is therefore only suitable for short use at intervals, such as signalling bells, wherein the manganese gets time in the intervals to absorb the hydrogen.

The improved cells made by Le Carbone Company have for their object low resistance and constancy over long periods of discharge.

This is obtained by using large zinc surfaces, plenty of solution, and a large quantity of manganese binoxide of high quality,

Low resistance is also obtained by using jute sacking to keep the manganese up instead of an earthenware pot.

The cell called the sack cell is illustrated in Figs. 191 and 192.

Fig. 191 is the common sack cell, outer jar $7\frac{1}{2} \times 7$ inches, 0.35 ohm resistance.

Fig. 192 is the largest cell of this type made; it is $8\frac{3}{4} \times 5$ inches, and 0.2 ohm resistance.

For larger currents and smaller internal resistance, the author prefers the arrangement shown in Fig. 193 — three or more sack elements immersed in one large vessel of solution, their zincs coupled together, and their carbons coupled together, so that they form one large cell. If three elements are used, the resistance will be one-third; if four are used, the resistance one-fourth that of one.

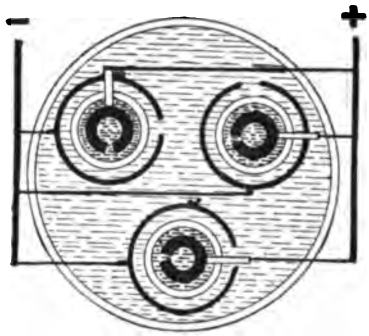


FIG. 193

The junction of the connections should be soldered.

In another type by same firm the carbon is an outer vessel, perforated and containing the manganese inside, forming an annular lining, the zinc being inside of the manganese, but prevented from touching it by a perforated inner porous tube, as shown in Fig. 194.

This arrangement places the materials in the best possible position for action, as the hydrogen, if any at all reaches the outer carbon, must pass across the manganese.

FIG. 194.—"Lacombe" Central Zinc Cell

Figs. 195 and 196 show a sealed cell and a dry cell by same makers.

Dry cells are so called probably because they are not dry. Properly speaking, all dry cells are moist cells.

They are mostly Leclanche cells with the electrolyte held in sawdust, or other absorbent material, which holds by capillarity.

In all forms of these manganese cells ammonium chloride, sal ammoniac, is used in a saturated solution.

A cell without a substance designed to absorb the hydrogen is said to "polarise" when the collecting hydrogen stops its action, and the substance used to absorb the hydrogen is called a "de-polariser."

We have seen that all decomposition cells give back a transient current after the action is stopped.

This effect was first studied by Ritter, and he found that lead

plates in sulphuric acid solution gave back current for much longer time than other combinations.

This discovery was the foundation of the modern accumulators or storage cells.

Planté found that, by repeatedly decomposing the water and taking off the current, the plates took up more and more energy, and by repeating the charging and discharging and reversing the current many times he formed plates which took up a large quantity of energy, and consequently gave back current for a long time.

FIG. 195
Hermetically Sealed
Sack Cell

FIG. 196
Le Carbone Company's
"Sans Pareil" Dry Cell

He found one plate, the anode, became oxidised into peroxide by taking up oxygen liberated on it by the charging current.

The other plate became spongy, and on discharging the spongy cathode is acted upon by oxygen and sulphuric acid, forming sulphates and low oxides.

On charging again the anode is reoxidised, and the cathode reduced again to pure spongy lead.

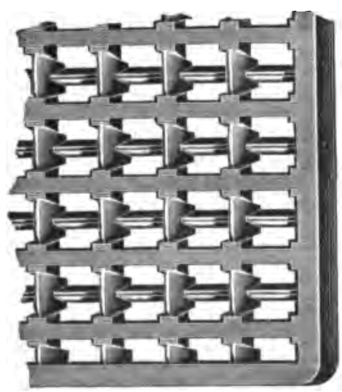


FIG. 197.—Section of Negative Grid

The Planté plate (the peroxidised one) is still used in modern accumulators.

M. Faure discovered that by pasting a mixture of red lead and sulphuric acid on the plates their capacity for energy became at once much greater.

Later on it was found still better to punch holes in the plates and fill them with the lead oxide paste.

And then grids and corrugated plates were used, all designed to carry a lot of lead oxide paste in contact with the lead as a conductor.

Fig. 197 represents a cast grid manufactured by the D. P. Company. A mixture of antimony and lead is used for the negative, as it is harder and stands the oxidising effect better than lead. The paste for this plate is made of litharge, mixed with a sulphuric acid solution of 1200 sp. g. Twadell, into a stiff paste, and then

pressed into the grid, and allowed to harden therein. When finished the plate is like Fig. 198.

The positive plate is shown in Fig. 199. It is corrugated or shelved on both sides, and the paste made of red lead, and solution of sulphuric acid of no greater strength than 1100 is to be used.

After the plates are thoroughly dry they are assembled into groups and fitted into cells.

The red lead plates are made the anodes and the litharge plates the cathodes, and attached to a charging source of electric pressure capable of giving 2.5 volts per cell to be charged.

The solution in the cells should be 1170 to 1190 sp. g. to begin with.

A small current must be used at the start, not more than one or

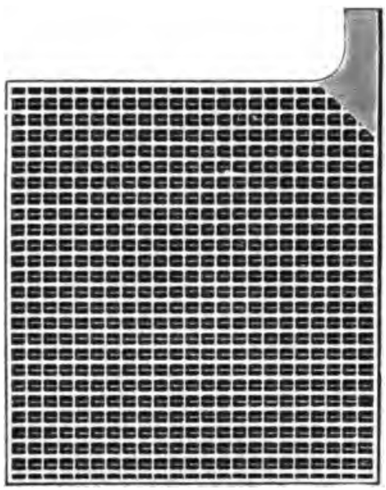


FIG. 198.—Negative Plate

FIG. 199—Positive Plate

two amperes per plate six inches square; the slower and longer the first charge the better.

If the student makes up a cell it should be one with three plates about 3 by 6 inches each. For this size the current to begin with should not be over 0.25 ampere, better only 0.1 continued for about forty-eight hours' charges without stop.

Lead wire gauze may be obtained, which when soldered neatly along top and bottom makes good amateur cells for experiments.

Later on the storage battery will be fully treated, as it is of great importance in electrical installations.

Gases can be acted upon electrically by the passage of the electricity as a spark or discharge.

Hitherto this action has not been applied to any practical purposes, except perhaps to the production of ozone. It is, however, from these neglected effects that practical improvements spring.

The silent discharge from the poles of an induction coil or influence machine through air condenses the oxygen into ozone, and this fact has led to the invention of apparatus for so producing ozone. The peculiar odour of ozone can be recognised in the presence of a working influence machine, due to the silent discharges going on producing ozone.

Fig. 200 illustrates an apparatus for the production of nitric acid by passing a stream of sparks through compressed air by an induction coil.

A barometer tube has a wire of platinum sealed into its short limb, or passed through a tight-fitting rubber cork, to cause sparks to pass when connected to the coil: the end of the wire should be rounded and polished.

Mercury is poured in to fill the short limb nearly full, holding the tube vertically. The tube is then inclined like this letter as far as possible without spilling the mercury; a few drops of water are now introduced into the short limb, to cover the surface of the mercury by a layer of water; the water should be coloured by litmus. While the tube is still in this position, insert the cork with the discharge wire (it must be a good tight fit), then slowly raise the tube to the vertical, and clamp it at that.

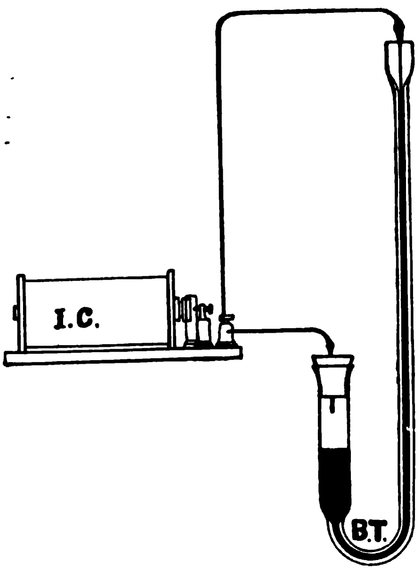


FIG. 200

The mercury will return to the short limb to some extent and compress the air enclosed therein between the cork and water layer. On passing the sparks through the compressed air the oxygen and nitrogen will be combined, forming nitric acid; the acid gas will be absorbed by the water, and the change in colour of the litmus will indicate its presence.

Again, if we produce very high electric pressure by induction coils between two terminals in air, a discharge occurs like a flame from the poles.

There are two kinds of combustion or combination of elements as gases, when ignited electrically.

First, like hydrogen and oxygen, wherein the combination gives off heat sufficient to produce a temperature to maintain the combustion. Thus, if a jet of hydrogen is thrown into the air, it does not burst into flame, because the temperature is too low to effect combination with the oxygen; but if it is once ignited it goes on burning, because the temperature of combination is more than maintained. Hence, also, if we fire a small spot or spark in an atmosphere of hydrogen and oxygen, the combustion instantly spreads throughout the whole atmosphere, for the combining temperature is generated right through the mass by its own combustion.

But nitrogen combining with oxygen does not give off enough heat to keep up the combination; it must get heat from outside sources to keep up the combustion, otherwise the combustion, or combination, ceases.

In the experiment shown the sparks heat the oxygen and nitrogen in the air sufficiently to enable them to burn together, but only those molecules which actually are in the path of the current combine, for the heat only concentrates upon those in the discharge path, consequently the air does not explode with a violent combination, even although we have fired a streak of air in the vessel by the spark.

Had oxygen and nitrogen, as mixed in our atmosphere, been like oxygen and hydrogen, then the first man who fired the first oxygen and nitrogen flame would have deluged the world in nitric acid fumes.

The sparks also bring about decomposition as well as combination. Ammonia and olefiant gas are decomposed by the sparks.

These cases are mentioned here, for it seems the electrolytic effects on gases have yet to be made practical use of.

The chemical combinations and decompositions by means of combined electrical and heat action, have now reached a very important practical position.

This process, which can very well be worked on a small scale in the engineering laboratory, consists in mixing the materials as a fine powder with carbon, passing current through the mixture to produce intense heat; when a certain temperature is reached, decomposition and combinations take place, and new compounds are formed, leaving perhaps an element free.

Fig. 201 is an illustration of an electrical furnace; it consists of a central carbon crucible, resting on a carbon block connected to the negative pole, so that the crucible is the cathode.

The anode is a thick carbon rod sliding through the cover of the crucible. The cover is of fire-brick or porous fire-clay.

The crucible is packed into a brick chamber surrounded by powdered bricks of fire-clay to confine the heat.

A fire-clay tapping tube is used to run off metals freed in the process.

Electrolytic Forge

The electrolytic forge, the electrolytic current interrupter, and the electrolytic alternating current rectifier, are recent developments discovered by experimenters, and indicate how useful discoveries are within the reach of those who can *devise* experiments, as distinguished from those who can only repeat experiments devised by others. The electrolytic forge is, to those who see it worked for the first time, something magical. In ordinary forges the smith cools his iron by plunging it into water, but in the electrolytic forge he plunges his iron into water containing some salts to make it an electric conductor, and the iron immediately becomes white hot under the water. The vessel containing the water solution is an electrolytic cell. In the bottom of the cell a lead plate is laid covering the whole bottom of the cell, and a broad strip of lead runs up to the top of the vessel to make electrical connection with the generator; this plate is the anode. A conducting bar is fixed along the top edge of one side, for the purpose of making contact electrically with the bar of iron to be heated. If the bar is long it may rest on this contact while dipping into the liquid, or if short the tongs may rest on this bar. The article to be heated is the cathode pole in the cell. Special Plate No. VII. illustrates this forge.

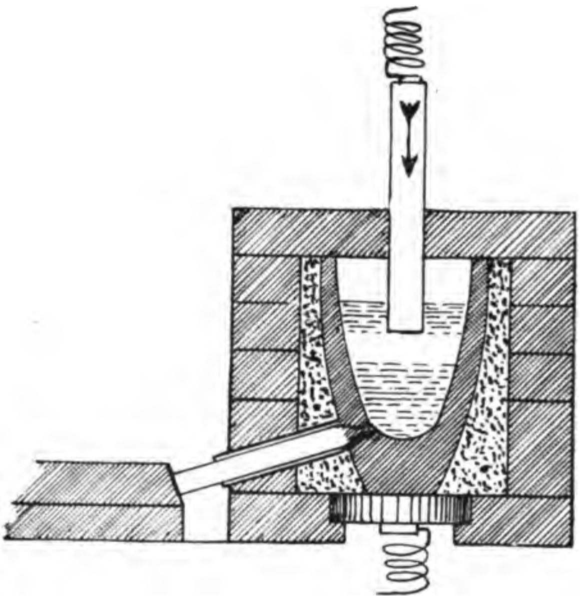


FIG. 201.—Electric Furnace

From 120 to 250 volts is required, and the anode must be at least a hundred times greater in superficial area than the article to be heated. This is necessary for economy, for we want no heat generated except at the cathode. It is the concentration of large current on small surface at the cathode which generates the great heat there.

The solution may be sulphuric acid and water 1150 sp. g., or, better still, an alkaline solution of bicarbonate of soda and borax in water nearly saturated.

The article to be heated must be connected to the negative pole *before* immersion. This is important, for if dipped in first, and then

connected, the heat generated will not rise above the boiling temperature of the liquid. What happens when we connect the cathode and then dip it in is this. The moment contact is made with the liquid, gas is formed at the point of contact—hydrogen gas. This gas immediately drives back the liquid, and an arc is formed across the gas from the liquid to the metal, and this arc extends as the article is more and more immersed. It is this extensive arc which does the heating. And the heating is uniform, for the hotter parts drive back the liquid farthest, so that the cooler part gets most of the current until uniform heating is attained.

The heat rises very rapidly to an enormous temperature, and melts iron, platinum, and any other conductors.

An American firm make a speciality of these electrolytic forges.

The electrolytic current interrupter (Fig. 202) is used for breaking up a current into an intermittent one of great frequency, and is used instead of the electro-magnetic make and break familiar to us on induction coils. A simple apparatus consists of a lead cell C containing an electrolytic solution of acid or alkali, and making it the cathode, while we use as an anode a small point — the end of a platinum wire sealed through a glass tube P. In this apparatus considerable pressure is also required — 100 volts or so — but by special construction much less can be used. In this apparatus the high pressure on the anode point drives back the electrolyte, immediately breaking the current; but the electrolyte falls back upon the point, to be again repelled. This happens at an extremely rapid rate, making and breaking the current hundreds of times per second.

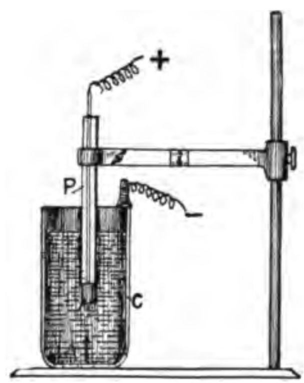


FIG. 202.—Electrolytic Current Interrupter

The electrolytic rectifier is of considerable interest, and will well repay close study and further experiments. It operates by presenting a great resistance to the passage of a current in one direction, and allowing current to pass easily in the opposite direction. The current to be rectified is alternating, flowing alternately in opposite directions, and the object of the rectifier is to allow currents of one direction only to pass. The aluminium cell has been mostly used for the purpose, but other cells exhibit the same properties; the effect is not so novel as most people imagine.

A silver and lead couple will present a high resistance in sulphuric acid and water solution when the lead is anode and the silver the cathode; but when the current reverses, and the silver is

the anode and the lead the cathode, the resistance is much less; hence, while small current passes in one direction, large current passes in the other direction. When the lead is anode its resistance is 207, and the cathode silver, 108; total = 315. When reversed the lead's resistance is 96, and the silver 44; total = 140, less than half the resistance in one direction than that when the current is in the other direction.

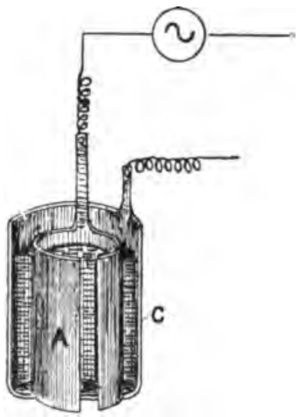


FIG. 203.—Electrolytic Rectifier

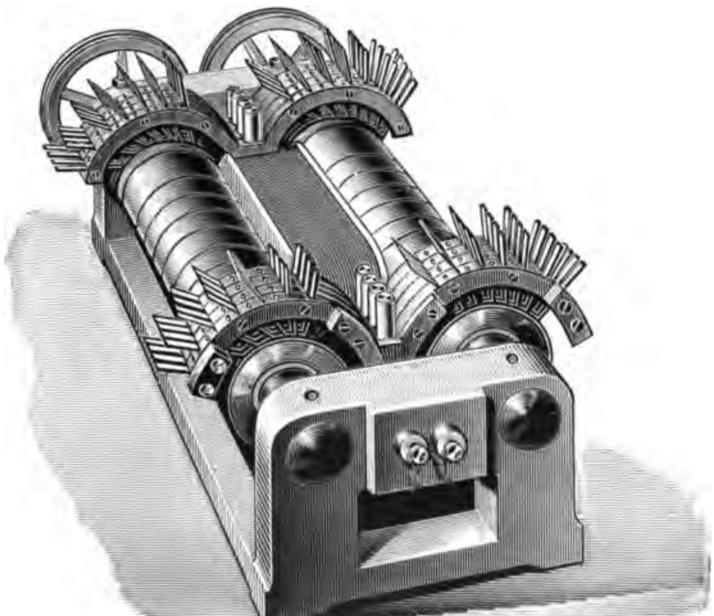
The advantage which aluminium possesses seems to be that its resistance is very high, much higher than any other metal or conductor in one direction, and very low in the opposite direction.

The subject is obscure, but of great interest in alternating current electrolysis.

The electrolytic rectifier (Fig. 203) consists of a lead cell C with an aluminium electrode A in a sulphuric acid solution. Aluminium, it seems, instantly becomes covered with a non-conducting film the moment it is anode, and the moment it becomes cathode this film breaks down and allows the current to pass.

Both these apparatus become hot in operation, hence many devices are made for cooling them. Thus to electrolysis we are indebted for such useful appliances and arts within the electrical engineer's scope — electroplating, electrotyping, electro-refining of metals, electro-extraction of metals, electro-chemical production of chemicals and gases, electrical forging, storage cells, alternating rectifiers, continuous current interrupters—and we all look hopefully to the time when by electrolysis we can liberate electrical energy direct from carbon.

ELECTROLYTIC FORGE



SIEMENS' ORIGINAL NON-POLAR DYNAMO FOR ELECTROLYTIC WORK

CHAPTER VIII

INSTRUMENTS, METERS, LAMPS

THE electric lamp is the one thing in electrical engineering which from the beginning presented no great difficulties. Long before the dynamo was brought to any useful shape the arc lamp was persistently experimented upon with a view to regulate its burning. The ideas of these ancient electricians are still the ideas of present-day arc lamp makers; they first found that if the two wires from a large battery of cells in series were armed with carbon points brought together and then separated, a bright light burned between the points. They also found that if the points were drawn too far apart the light went out, and that if the carbons could be kept the same distance apart by moving them steadily towards each other at the same rate at which they burned away a perfectly steady light of great brilliancy could be maintained, and apparatus were invented for holding the two carbons, drawing them apart the proper distance, and feeding them together at the proper rate. All this was found out between 1840 and 1859, as a reference to the Patents Office will prove.

In these days only primary batteries could be got to supply the pressure and current; hence, although the subject was fascinating, it was dropped on account of its small commercial value to the inventors and their patrons. For twelve years electric lamps made no further progress; during that time the Serrin lamp, invented in 1857, and the Duboscq lamp, invented in 1858, were the only ones in the field. But with all their drawbacks these old electricians had discovered all the principles of regulating arc lamps automatically, and found mechanism, coils, and magnets to carry the principles into effect.

But the principles which govern the working of arc lamps in series or in parallel, a large number from one generator, were unknown to them, for having no generators of sufficient power to run more than one lamp, the problems did not arise. They, however, found that the arc would burn in a vacuum, and also under water.

The perfecting of the dynamo by M. Gramme and Von Alteneck placed the electricians of 1876 to 1882 in a position to run many lamps from one generator, and very soon they found, first, the laws of the series lamp, and later the parallel lamp regulation; and strange

as it may seem, the improvements required to fit the arc lamp for either circuit were exceedingly slight, so simple that they are scarcely visible.

The incandescent lamp dates away back to 1845. Its history is exceedingly interesting from the fact that it determined the great electric lighting movement which began in 1882 as a result of the successful manufacture of incandescent lamps by Swan and Edison, to whom all credit is due for perfecting that manufacture sufficiently to make it a commercial success. But Starr and King had invented an electric lamp consisting of a carbon conductor in a vacuum nearly fifty years before, so that the bold claim made by the holders of the patent rights for the new lamps that they claimed as their invention, a carbon filament in a vacuum, is untenable. The question was raised in the law courts, and the contest raged around the word "filament": What is a "filament"? Wherein does it differ from a long thin rod? The early inventors had used rods of carbon as thin as they could possibly make them; but as they made them by cutting out of solid carbon the degree of thinness attained was not great, but still they made them as filamentous as they knew how. What the Swan and Edison patent specifications disclosed as new to the world was not a lamp with carbon heated by an electric current in a vacuum; that had been done by Starr, King, and Konn long before. Really what they did describe was a process for producing carbons much thinner and longer than could be produced before and by a really new and valuable process. They took a vegetable fibre of cane, or cotton, or paper, principally constituted of carbon, and which could be shaped to any figure, and as long and thin as desirable; and by enclosing the shaped vegetable fibre air-tight and packed in powdered coke or lamp-black in crucibles, and raising the whole to a white heat for some hours, upon cooling and opening up the crucibles the vegetable fibres were found to be converted into carbon, retaining the shape and size which had previously been given to them. This process it was that made incandescent lighting a success; but soon after its success inventors discovered other processes for producing carbons quite as thin and long, and of any shape, without the vegetable fibre and the roasting in the crucible; but these processes were not allowed to be used in this country, as the courts, under the expert evidence given, allowed the claim for the filament itself, however produced, and all progress stopped for a time in incandescent lighting. The lamps improved in manufacture, but remained at pressures of 110 volts and under for many years; in fact, many places had large installations, actually planned and carried out under what was supposed to be expert guidance at great expense, to fit the 100 or 110 volt lamp. Much in the same way as the man who bought a window-frame, and had the house built to fit it.

Later on, however, the folly of working at 100 or 110 volts became apparent, even to the experts, and lamps were forthcoming of 250 volts pressure; then the systems of installations were changed over to that higher pressure, effecting great saving in copper mains, to supply the lamps. But experience of these lamps shows that they have a shorter life and a lower efficiency than the old ones had at lower pressures, so that there is room for improvement yet. And further, the three-wire system so much in use was devised to meet the low-pressure incandescent lamps, and 110 volts was chosen because two arc lamps in series could be very well worked at that pressure. Now, however, that higher pressure lamps can be got, it becomes a question whether the use of a three-wire system is not due more to force of habit than to common-sense reasoning. Later on we shall have to inquire into this. Meanwhile it may be remarked that the experts who adopted it argued that it saved copper in the mains, and that the lamps on each side need not be equal in current consumption; in fact, they said it balanced naturally. But nowadays we don't hear much of this theory; in practice it does not seem to work. The best proof of this fact is given by the very solid arguments in the shape of "Balancers" on every three-wire system, and other expensive arrangements, which go far to swallow up any saving of copper in the distributing wires, not to speak of the complications in connections introduced by the three wires.

The question is: If the three-wire system fulfils its purpose, where do the "Balancers" come in? They come in only to help out old systems laid down in ignorance and found defective, and such is the force of example blindly followed that we actually find them included in absolutely new installations. One of the objects of the succeeding volumes of this work is to make plain the use and also the "abuse" of apparatus and methods in electrical installations, hence these elementary facts are given here. It will be seen that no small part has been played by the lamps in electrical progress, and they are still the commanding factor in the problem of further progress. But there can be no doubt that such a crude method of lighting as that of the carbon filament, which produces light while wasting 90 per cent. of electrical energy, cannot be the final lamp. Already we have in the Nernst lamp and the Mercury Vapour lamp indications of "new lamps for old" incandescent ones.

In arc lamps the only recent improvement is that called the Enclosed lamp, wherein the arc burns in an air-tight globe, so that the consumption of carbon is much lessened, thereby reducing the cost of carbon and attendance; but it does not give the same amount of light for the power consumed that the open air-fed lamp gives. The idea is by no means new.

Switches and Fuses

Switches are to the electrician what stop-valves are to the steam hydraulic engineer, and have quite a brief history; in fact, they have only just reached a practical stage. At first they were designed and made by philosophical and scientific instrument makers, with an eye to polished and lacquered brass, and no idea of wear and tear, and less about resistance.

It would surprise some people to see the results of measurement of drop in pressure in various switches. Every switch should have clearly marked upon it the drop in volts across its terminals when the full current for which it is sold is passed through it, and it should be guaranteed to work for a time without increase of internal resistance. The *internal resistance* of a switch may seem a queer thing, but it is quite as real as the internal resistance of a battery, and more important.

The first considerations in their design should be low resistance at contacts, and durability. Yet British manufacturers have not paid much attention to them, many firms making and selling motors without switches or fuses, not even being able to recommend a suitable switch. The best foreign firms can always supply with their motors a complete switch-board with ammeter, starting switch with automatic cut-off, double pole switch and fuses, and a discharge resistance, all of which are necessary and need not be costly.

It is a great recommendation for a motor when an engineer or contractor is in the market as a purchaser to know that when it is delivered it will be complete, and that he will not require to forage around for half-a-dozen details required before it can be set to work. Owing to this defect many a failure of motors is due, and yet this slovenly practice goes on among smaller firms. Important firms cannot afford to take such risks, and therefore always include every requisite in the way of switches, cut-outs, and instruments in their tenders, leaving it to the purchaser to strike them out if not wanted.

The same may be said of fuses. They are, as a rule, badly designed and far too expensive; but every year sees improvement, and now that higher pressures are in use, and not likely to go higher still, some standard forms may be arrived at. No doubt they will be all made for the maximum pressure, 250 volts; at least one would naturally think so, but considering the fact that uniformity in practice in electrical engineering has hitherto been conspicuous for its absence, this may not be done. In continuous current systems we find them fairly uniform at 100 to 110 volts at first; then when the higher pressure became fashionable, instead of all going to the one pressure each went his own way, and now we have 200, 220, 250

volts installations. In alternating current systems there is more scope for diversity, hence more diversity. Not only have we installations at all pressures from 100 to 250, but we have all manner of frequencies from 120 down to 40 per second. All this chaos in electrical installations is due to their rapid growth to some extent, to the rivalry of competing systems, and want of knowledge by those who designed them. Many installations have been entirely reconstructed before they were ten years old. And these diverse systems have much interfered with the perfection and standardising of details, such as switches, fuses, and instruments, as well as in greater things, such as lamps and motors.

Supply meters are special manufactures, and are simple machines. Although much difficulty has been met with in devising a form entirely satisfactory, there can be little room for doubt that at last a motor meter, suitable for either continuous or alternating current and without any fluid, will finally prevail. But even here the electricians are far from agreed as to what method of charging consumers for supply is best; and some very questionable proposals have been made and carried out, principally by station engineers, giving rebates and preferences to the best paying consumers. This practice, while quite legitimate when the supply is given by a private trading concern risking its own capital, is not so when practised by a municipal concern using public rates for the purpose, upon which every member of the community has a right to call for equal treatment. It may be replied to this that if the concern pays its way without drawing upon the rates or upon the public purse in any way, then it has the same rights as a private company to make its own rules for supply and payment therefor. However, this question only interests us here because, instead of a plain meter record upon which the supply is paid for (like gas at 2s. 6d. a 1000 for everybody), we have to add maximum demand meters, or double meters, and other complications in installations. There are successful meters called motor meters; they, when studied closely, will be found to be motor generators on a small scale, built with an eye to reducing friction to the smallest limit. The so-called magnetic brake is a generator with a short circuited armature, the old Faraday disc generator, the first dynamo ever made. In one meter both motor and generator are of this type; the motor armature is connected in series with the load, and the field of both motor and generator is constant and provided by a permanent magnet. The action of such a meter is clearly on ordinary dynamo-electric principles, and can be nicely demonstrated by coupling a pair of little toy dynamos shaft to shaft, short circuiting the armature of one and applying a pressure to the other armature through a variable resistance

and an ammeter. The fields must be separately excited constantly. By this experiment it can be shown that the speed is proportional to the current in the dynamo armature. Double the current doubles the speed, but no more, for the current induced in the generator is also doubled, and therefore takes double the torque also. Now it has always been argued that this so-called magnetic brake did not act as the square of the speed; but that is a mathematical fallacy plainly to be seen, for if we double the *torque* and double the *speed* of a motor, the *power* is not doubled, but squared, in a constant field. Hence the generator requires also the square of the power to drive it at doubled speed. It is because both follow the square law that the speed is proportional to the current in the motor armature.

The foregoing is the true science of the motor and brake meters commonly in use, correcting the error in the law of the brake.

In another meter successfully used the motor has a constant current in the armature, and a variable field in series with the load. The generator is on a constant field. In this case the speed is same as before, proportional to current passing in the motor—this time through field of the motor. If an ammeter and a voltmeter are applied in the motor circuit, the speed will be proportioned to the current. Hence, the electrical and mechanical laws are in perfect agreement. Mechanically, if we have twice speed at twice torque, the power required must be as the square. Guthrie and Boys describe tests on the magnetic brake in the *Proc. Physical Society*, 1879, by hanging a copper disc by a torsion wire above a rotating powerful magnet, and they found that the torsion was directly proportional to the speed of the magnet. But they did not measure the *power* required to run the magnet at the different speeds. Evidently they took it for granted that every one would know that if the torque was proportional to the speed the power exerted would be as the square of the speed.

These considerations are of great importance to students and investigators, for correct notions throw floods of light on obscure problems.

This explains why the Schallenberger meter, which has an air brake in shape of a fan, works as well as the magnetic brake in a meter.

The complete theory of meters is very complicated, for they are so delicately poised that effects which, in ordinary motors and generators, are either negligible or perfectly well known and measurable, have immensely magnified effects in these delicate machines in meters. Counter E.M.F. and friction play parts quite beyond calculations, and tolerable accuracy is attained by experiment and tests and adjustments only.

The insane craze for accuracy at low loads on, say, one 8 C.P. lamp has produced meters which may pass the test when new, but which soon get out of accuracy at all loads—a much more serious affair than, say, a 20 per cent. error on one lamp.

The supply meters in use are of many types at the present day, and we need not here refer to the vast number of variations brought forward from time to time. The first and oldest type of meter is the electrolytic meter, wherein metal or gas is deposited or liberated in proportion to the current used by the consumer.

Edison worked long on the electrolytic meter, and used two amalgamated zinc plates in a saturated solution of zinc sulphate, and by shunting a small known fraction of the current through this cell a certain amount of zinc was transferred from one plate to the other, proportional to the consumer's current; the difference in weight gave the units to be charged for. This cell was liable to error from differences of temperature and from back E.M.F., and the weighing of the plates was troublesome, and not looked upon with favour by the consumer. Edison, by hanging the plates from a balance and attaching an automatic recording device, attempted to make it read off units consumed direct.

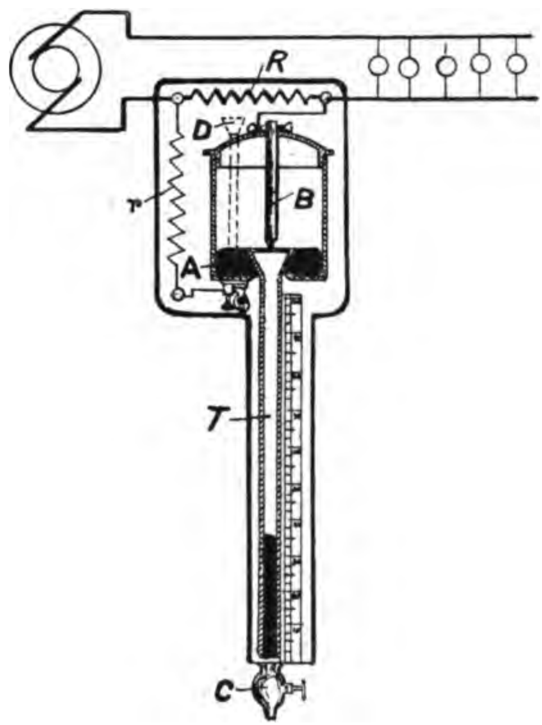


FIG. 204

A diagram of an electrolytic meter showing a very promising principle of action is here given in Fig. 204, as one example of electrolytic principles applied to measuring ampere-hours.

The cathode is a carbon rod, B; the anode a layer of mercury, A, in a cell; the cell has a barometer tube, T, dropping downwards along a scale of units. At the end of the tube is a tap, C, whereby the mercury may be drawn from the tube and returned to the cell by a funnel. The cell is connected across a fixed resistance, R, in series with the load, so that a small portion of the current passing is shunted through the meter. A second resistance, *r*, is in series with the cell for the purpose of adjusting the

meter to read Board of Trade or other units. The action is simple: the current deposits mercury on the carbon rod, which does not adhere; it drops off into the tube, rising there to indicate the consumption of current in the circuit on the vertical scale.

The earliest proposal for a clock meter was made by Professors Ayrton and Perry, who designed a clock with a coil carrying part of the consumer's current, forming the hob of the pendulum. This coil was pulled downwards by a second coil, thus adding to the effect of gravity and accelerating the clock. The difference between correct time and the measuring clock gave a measure of the current consumed. Arons' meter consists of two clocks connected by a differential gearing, which drives an index train of wheels indicating directly the units consumed. Each clock has a pendulum; one is slowed and the other accelerated by the consumer's current, and the difference is proportional to the current consumed or watts consumed.

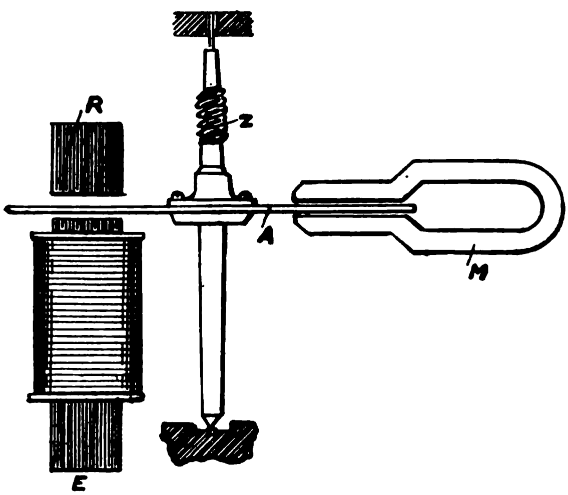


FIG. 205

Perhaps the most numerous class of meters in use are motor meters, in which a motor runs at speeds proportional to the current, the motor being resisted by the force of some brake. Two examples are shown here in diagrams. Fig. 205 is a side elevation, Fig. 206 an end elevation, and Fig. 207 a plan. A spindle, Z, has a worm to gear into a registering train of wheels, and a copper or aluminium disc, A, is mounted free to rotate on jewelled bearings. A three-pole alternating magnet, S_2, H, S_1, is fixed below the disc as shown, connected to the circuit. This magnet has a main and shunt winding, whereby it acts upon the disc and drives it round as a motor, with a torque proportional to the current in the main thick wire coils.

A permanent steel magnet, M, embraces the disc as shown, and when the disc rotates under the torque set up by the alternating magnet, currents are generated in the disc under the steel magnet. Thus, on one diameter the disc acts as a motor, and on the opposite diameter it acts as a generator. The whole combination is a motor-generator, and it is well known that a motor-generator runs at a speed proportional to the current in the generator when the motor armature is short-circuited.

Many meters depend on this principle, but the disc cannot always be used for the armature common to both motor and generator. It can only do so with alternating currents, whereby motor currents can be induced in the disc. Continuous current requires a continuous current motor apart from the generator, but otherwise the principle is the same. A meter for continuous current is shown in Fig. 208; the disc and steel magnet M form the generator, or so-called disc brake or magnetic brake. The motor armature is shown as a coil S mounted free to rotate and fixed on the same shaft A as the generator brake. In this type of meter a commutator K is required to operate the armature; but it has the advantage over the one with a single disc acting as motor and generator, inasmuch as it is suitable for both alternating and continuous currents. In this form of meter the moving coil is a shunt circuit constantly excited to the same extent, and the fixed coil or coils H carry the whole consumer's current for measurement.

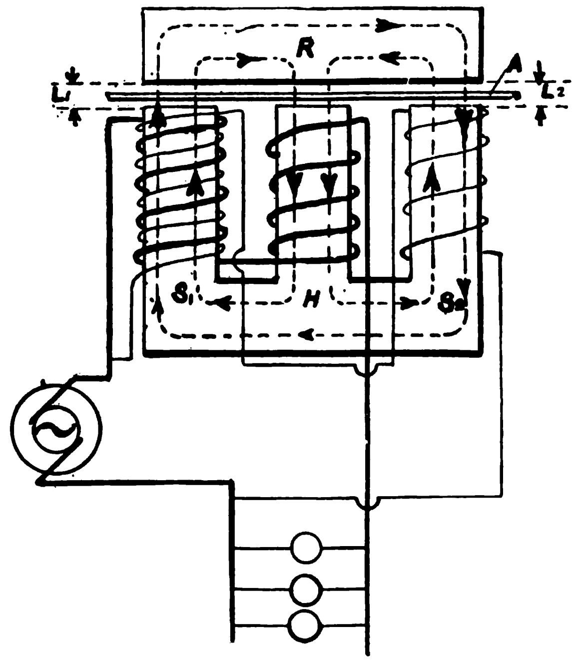


FIG. 206

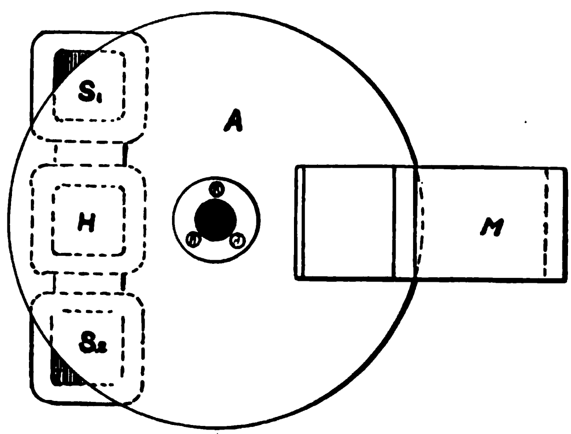


FIG. 207

And it is customary to put a small coil inside of H, and in series with the moving coils, in order to assist in starting and overcoming friction on small loads.

In another form of motor meter a bath of mercury in the form of a disc is placed between two powerful magnet poles, *i.e.* in a

strong magnetic field in which the lines of magnetism run through the mercury disc parallel to the axis. The whole current to be measured passes from the circumference of the mercury to the centre radially; hence the mercury is driven round and revolves with a speed proportional to the current, for the fluid friction is as the square of the speed, and the power driving the mercury is as the square of the current.

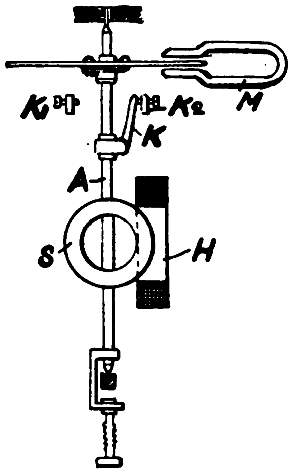


FIG. 208

There is, however, in these mercury meters, where the consumer's current makes a short path in a strong field, very small power at low loads.

The Ferranti meter, on this principle, was the first of its kind successful; the mercury is motor and brake in one.

In regard to supply meters, the losses due to errors in the meter are worthy of consideration here. An example will show how the losses are really obtained from calculations made on the percentage errors in a meter at different loads.

Percentage errors are very misleading to the superficial reader of a meter test. Take, for example, a meter for fifty 8 candle-power lamps, which does not move at all with one lamp on, as an extreme case of a meter inaccurate at low loads; and at high loads, say, this meter has an error of only 2 per cent., being correct about half load. Each lamp takes $\frac{1}{30}$th of a unit per hour, so that running for thirty hours the company, or supply, loses the price of a unit for every thirty hours when only one lamp is on; total loss, say, 4d.

But calculate the loss at full load for an error of only 2 per cent., fifty lamps will take 50 units in thirty hours, and 50×4d. = 16s. 8d. Sixteen shillings and eightpence would be the cost. Two per cent. on 16s. 8d. is, as near as possible, 4d.; so that, with only 2 per cent. error at full load, the loss is equal to the loss on low load at 100 per cent. error; and a 2 per cent. error at full load is just as bad as giving one lamp for nothing at low load.

It is well, of course, to aim at high efficiency and economy in all engineering work; but figures do not always convey facts. From the above reasoning, it is clear that some definite criterion of a meter's performance is required. It is too much to expect an instrument which must act under minute forces, to be of cheap construction, and work closed up in a cellar, and be absolutely correct. In the first place, an error of 2 per cent. on either side of the correct line must be accepted as a common-sense, practical condition, and after

all this does not count for much, for some meters are low and some high in error; consequently, the aggregate result is nearer correct than one would imagine. The question of importance is to fix the point in the meter load where the readings should be correct. There is no reason why any meter should not be correct at quarter load, and remain correct from that up to full normal load, with a slight rise on over-load. From quarter load down to $\frac{1}{10}$th load 2 per cent. error may be allowed with safety on either side; from $\frac{1}{10}$th to $\frac{1}{20}$th of full load, 5 per cent. error; and below that load, except on very small meters, the error is not of any consequence.

Meters should not be put in too large for the circuit: it is better to run them occasionally overloaded than to run them continually underloaded.

Different types of electricity meters have different characteristics. Perhaps the type most likely to give a straight line characteristic are those in which the motive force is applied independently, apart from the measuring circuit. The clock meter, invented by Ayrton and Perry, is an example of this type; so is the Aron meter, and others to be referred to; also the author's meter, in which there is a motor circuit and a measuring circuit distinct from each other.

Two diagrams of characteristic curves are here given, taken from tests made on meters in actual use. Fig. 209 is from a sample of a

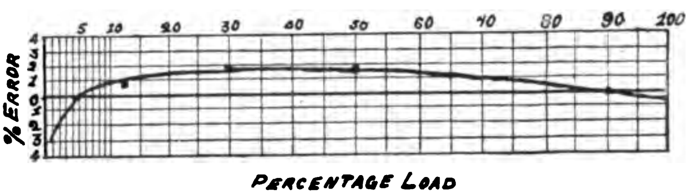


FIG. 209

much-used meter. The straight zero line is the line which should be found. The curve is the actual line found. It will be seen that at working medium loads, it is about 2 per cent. wrong in favour of the seller. A little under full load it is correct between 8 and 9 amperes; at 10 amperes it is nearly 1 per cent. wrong in favour of the buyer. At low loads, from .5 downwards, it is again in favour of the buyer. This diagram is very good at the small load end; in fact, the hump on the curve is due entirely to this attempt to get accuracy at low load. It is obtained by forcing up the power, thus causing the rise at middle loads.

Fig. 210 is a better curve, both for buyer and seller. On medium loads it is correct from 2 to 9.5 amperes, when it slightly rises. It is not so good as the former at low loads, but, as before explained,

that is far more than compensated for by the long straight line, upon which most depends.

The principles of the arc lamp are very simple, and may be illustrated by a few diagrams of the different types. The first is a purely

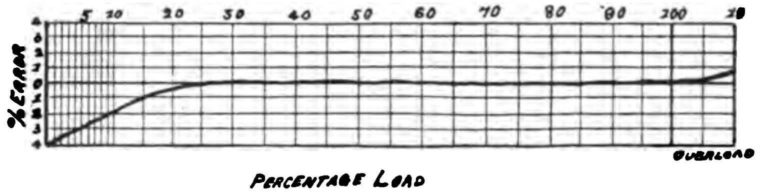


FIG. 210

electro-magnetic lamp, in which two solenoids, one in series with, and the other in parallel or a shunt across the arc. These two coils act oppositely. The series coil is of wire thick enough to carry the current; the other is a fine wire coil, calculated to run fairly cool on a 50 volt P.D. at its ends. The ampere-turns in the two coils should be equal each to each. The core of the solenoids is a conical core, so that the pull upon it is fairly uniform in any position. In Fig. 211, C is the bi-conical core which carries the carbon rod shown at *c* in Fig. 212, a horizontally working lamp. The main coil M pulls the carbons apart, thereby striking the arc light; but as the carbons part the resistance increases between the carbons, so that the P.D. across the terminals rises to about 45 volts. This

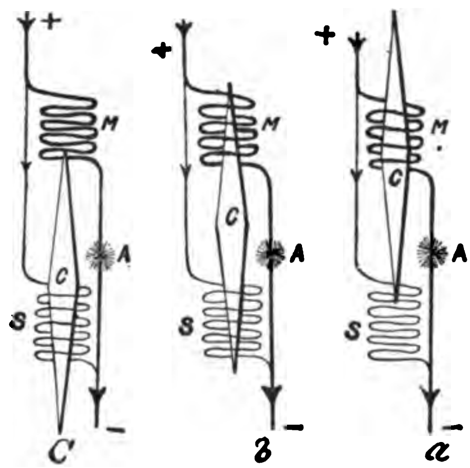


FIG. 211

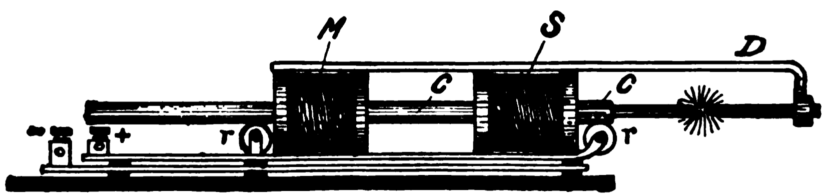


FIG. 212.—Pilsen Arc Lamp

P.D. sends a current through the fine-wire shunt coil S, which pulls against the main coil, till at last the core comes to rest at a certain position, where the pull of the two coils balance with the

carbon points about $\frac{3}{16}$ inch apart. But the carbons burn away, and the P.D. rises slowly across + and —, while the current slightly becomes less through coil M and the arc A; hence, coil S has the pull over M and moves the core C forward, to make up for the waste of carbon and keep the arc of constant length. In a good lamp this action keeps the carbons moving together steadily at the rate the carbons burn away, the variation in P.D. being no more than half a volt at the terminals. This kind of lamp is capable of a continuous feed of the carbons at the rate they burn away at, and is the only purely electro-magnetic lamp direct acting. In Fig. 211, at *a*, the core is in its first position when new carbons are put in; at *b* the core is half way, the carbons being half consumed; at *c* the carbons are finished. The bi-conical core is coned to produce an equal and opposite pull in any position of the core between *c* and *a* when the ampere-turns in coils M and S are equal. This is the principle of the Pilsen lamp.

Another common form of regulator for lamps is shown in Fig. 213 by diagram. It is a clutch regulator; the carbon rods R^1 R^2 are caught in a metal washer W^1 W^2. When the washer is tilted as at W^2 the rod cannot slip through; but when the washer is at right angles to the rod it slips through easily. Now when the current passes in coil *c* and through the carbon core, P is pulled up and lifts one side of the washers, gripping the rods and lifting the carbons apart. There are two carbons designed, one to burn after the other; and by the simple device of causing one washer to grip before the other, the arc is formed only between the carbons which are last parted. This difference is caused by making stop S^2 lower than stop S^1. Now as the carbon on R^1 burns away the core falls, and washer W^1 coming in contact with S^1 releases the rod and it slips through, thus feeding the carbon forward. The coils are wound differentially with a main and shunt wire acting oppositely to each other.

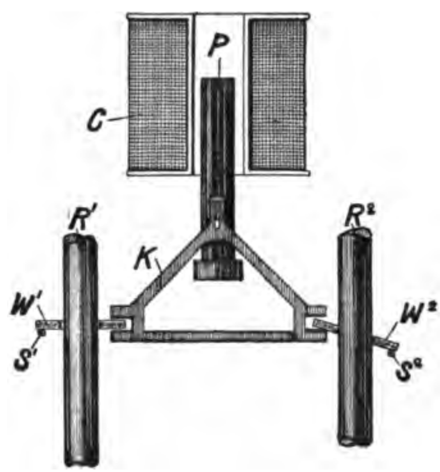


Fig. 213.—Brush Lamp

Fig. 214 is another diagram of a clutch mechanism designed by the author. The rod R carries the carbon and feeds through a washer with a tail on it and an adjustable screw H, and the washer is hung as shown over a small pulley, and over a larger pulley are hung two cores, P_1 and P_2. P_1 is acted upon by main coil M, and

P_2 by shunt coil S. The current in M pulls the clutch up and strikes the arc; the shunt coil pulls against the main coil, so that they balance when the arc is the proper length, and thus the arc is regulated. The main core has an iron mantle which gives greater power to the main coil to overcome the weight of the rod to be lifted.

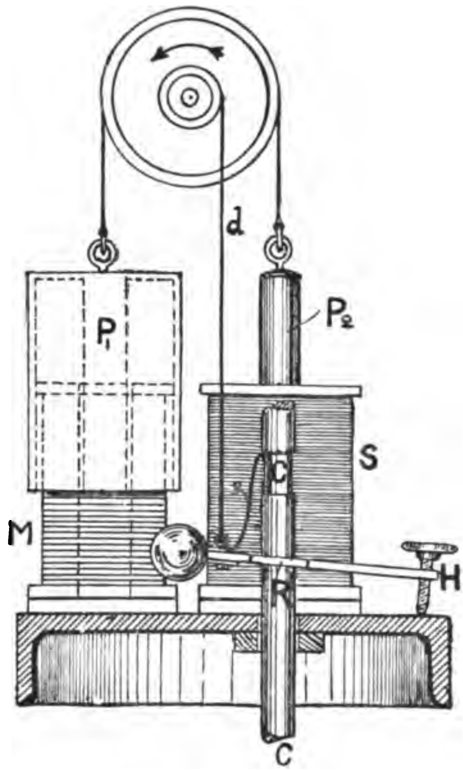


FIG. 214.—Arc Lamp Mechanism

Another class of lamp has a brake wheel which is gripped and turned round or lifted to strike the arc, and then allowed to slip and feed the carbons forward much as a clutch lamp does. The Brockei-Piell lamp is one of this type; also Crompton, Pochin, Mensing, Blahnik, Siemens, and others. In fact, the wheel clutch seems to have advantages over the clutch applied directly to the carbon rods.

There are also lamps in which the arc is struck and the carbons fed by little electric motors, a beautiful example being that of Henrion, in which an induction motor is used for an alternating current lamp.

In succeeding volumes these lamps as actually constructed will be fully described. Meanwhile we may refer to the vital parts of the arc lamp, the solenoids and cores. We have already referred to the Pilsen lamp coils, in which it is plain that the two coils, main and shunt, must have equal ampere-turns when the arc is formed, and also we have noticed how the core is skilfully designed to give equal effect throughout its stroke. But in most arc lamps, especially of the clutch type, which also includes the wheel clutch (so-called brake), there is very little evidence of scientific design in the coils and cores operating the regulator.

A core acting in a solenoid is not pulled upon uniformly in any position. As the core is entered the pull increases as it goes further into the solenoid until a maximum is reached, when the pull begins to grow less and less, and comes again to zero. This is shown in Fig. 215, where C is a coil and P a plunger. The length of the coil

is *a b;* the travel of the plunger *a E*. The length of the plunger must be equal to *D a b E*, where *D a* is equal to *b E*, or the plunger twice the length of the coil.

The maximum pull is just about where the ends of the coil and plungers coincide at *b*. If the plunger is projected beyond *b*, the

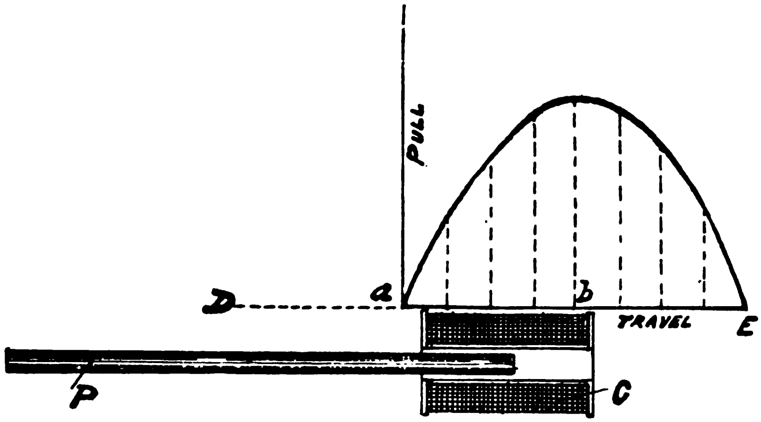


Fig. 215.—Diagram of Power in Coil and Plunger

pull becomes less and less till it is zero, when the plunger projects equally from each end.

Now the important question that arises in designing lamp coils and plungers, is, at what point in the pull curve should the end of the plunger operate? Should it be on the rise or fall side of the maximum pull?

A little consideration will prove that the main plunger M (Fig. 214) should start from the position slightly further into the coil than the maximum point, so that as the arc strikes the plunger moves into a weaker position, and therefore naturally tends to balance its position, even without the opposing effects of the shunt coil. Then the shunt coil should have its plunger start with its inner end also beyond the maximum point, so that, as the arc strikes up, the plunger moves into a stronger position of pull. Thus, when the arc lengthens, the shunt will, with but small increase of P.D., easily control the feed; and the phenomena of what is commonly known as pumping cannot take place.

Straight cores are usually too short in order to keep the lamp down in length, but cores should never be less than twice the length of the coil. A long core can be bent over into a horse-shoe, in order to shorten the space occupied. Coils should be about 5 to 7 diameters in length, the bore being the diameter.

There would not be so much call for such refined mechanism in arc lamps if the controlling magnetic apparatus were properly made and designed on these lines

Old Lamps

The only recent improvement in arc lamps is the burning of the arc in an inert atmosphere. The arc is formed in a closed air-tight vessel of glass, so that any air which it may at first contain loses its oxygen by combining with the carbon to form carbonic acid gas. There being no further supply of oxygen, combustion ceases, and the carbon wears away very slowly by volatilisation, and lasts, it is said, for 100 hours, instead of only 8 or 10 hours. Naturally, the enclosing vessel becomes very dirty and the light is obscured to a large extent, as there is no escape for the carbon débris, ashes, and dust.

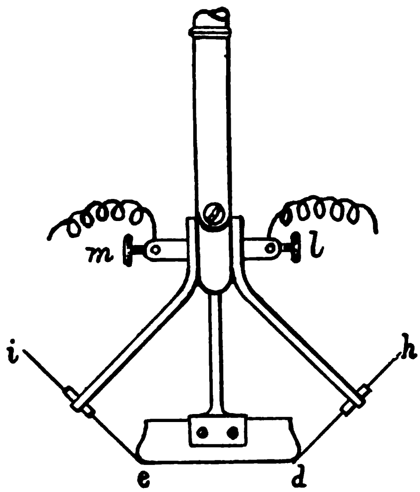


FIG. 216.—Jablockoff Lamp

Away back twenty years ago a beautiful electric lamp was made, working on a principle first introduced by Jablockoff. He used a thin plate of kaolin, or unglazed porcelain, as shown in Fig. 216. Two platinum wires, *i h*, held in two contact terminals, brought a high-pressure current to bear on the corners of the plate *e d*. The current had a pressure capable of sparking from *e* to *d*, and the spark was led from *e* to *d* by a carbon point held in the hand by an insulator, so as to start the light up, for the cold porcelain is a bad conductor. It gradually becomes heated, and as it becomes hotter, takes more and more current until the whole edge glows with a fine golden coloured light. It was not a success first, because it required that preliminary heating. It could be started with a blowpipe flame, or by a fuse match laid from *e* to *d*. Secondly, the heat spread into the plate and caused a large leakage of current, which gave little light.

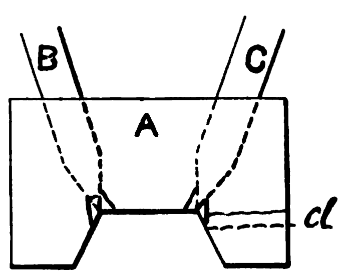


FIG. 217.—Sun Lamp

Following the same idea, we had the sun lamp shown in diagram (Fig. 217), two carbon rods, fitted through two holes in a marble block, A. To start with, the carbons B C were pointed and projected slightly through the block, and on being connected to a dynamo of 50 to 60 volts, the arc was started by a pencil of carbon projected through a side hole *d*, momentarily connecting the carbons.

The arc playing along the face of the marble raised it to a high incandescence, and the current passed mostly by the heated marble

face, which threw down a fine powerful steady light. It had the same drawbacks as the Jablockoff, only on a larger scale.

Following these, we have the Nernst lamp, illustrated here (Fig. 218), as made and sold by the Allgemeine Elektricitate Geselichaft. In this lamp the refractory material is made up as a thin rod, and to start the light the rod is first heated by a current in an iron wire spiral, this current being automatically cut off when the lamp lights up. The rods and spirals wear out in time, but can be easily replaced, as the lamp is open. Doubtless these lamps will be much used in the future, as they give about twice the light given by carbon lamps for the energy consumed.

Fig. 218
Nernst Lamp, by the Electrical Company, Charing Cross Road, London

Another promising lamp is the Cooper-Hewitt lamp, shown in Figs. 219, 220. Mercury is carried in the end of a glass tube at A, Fig. 220. A current of high pressure is required to start the light, after which it is maintained by a low-pressure current. The high-pressure current forms mercury vapour at a considerable temperature, and it is this hot mercury vapour which, when current passes through it, gives the light. The tube is $\frac{3}{4}$ inch diameter, 54 inches long, with a 3 inch bulb B. The electrode in the bulb is of soft iron. The efficiency of the light is very high, but has a great drawback, inasmuch as the light given is monochromatic, and, therefore, articles seen under it cannot be seen in their true colours.

Arc lamps may be regulated by either a shunt or main solenoid or magnet alone; but it is quite obvious that the variation of pressure required to operate a lamp by a shunt coil and the variation of current required to operate by a main coil alone must be at least double that required in lamps in which a shunt and main coil act both together, the pressure across the arc increasing while the current decreases. The combined action of the shunt and main coils effect the regula-

tion under a difference of pressure of only 0.5 volt and 0.5 ampere, while with either coil alone the variation would be at least 1 or 1½ volt or ampere.

The arc itself has a resistance which seems to be compounded of a counter-pressure and a small ohmic resistance. The counter electric pressure is supposed to be about 39 volts; hence if we apply 40 to 45 volts the arc is maintained, and a slight increase of pressure or decrease of pressure makes a vast difference in current. After 40 volts has been reached, the current is proportional to the small ohmic resistance of the arc; the arc behaves as if its resistance were about $\frac{1}{10}$th of an ohm only; hence a slight change in pressure causes great fluctuations in current and unsteadiness. When two carbons are brought together, coupled direct to a supply at 60 volts, and separated to form an arc, the unsteady working is due to this back pressure and small resistance of the arc. In order to prevent these great fluctuations in current in arc lamps, it is necessary to add resistance to the lamp circuit when they are in parallel connection to the mains; about 1.5 ohm is usually required for each 10 ampere lamp, and 65 volts applied. We thus get the working conditions as $65-39=24$ volts expended on the ohmic resistance and 39 on the counter electric pressure; and of the 24 volts, 15 are expended on the resistance in series with the arc and 9 volts on the resistance of the arc itself. The action of the resistance will now be evident. If there were no resistance in series, $39+9=48$ volts would run the arc at 9 amperes, but the slightest change in the arc would cause a great change in current. The resistance being only $\frac{1}{10}$th ohm, a change of 0.01 ohm would cause a difference of 1 ampere; but if we add 1.5 to the 0.1 we get resistance equal to 1.6 ohm, so

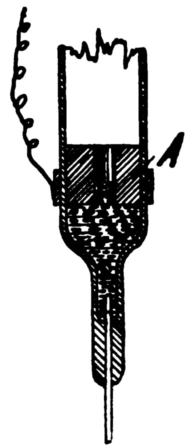


FIG. 220

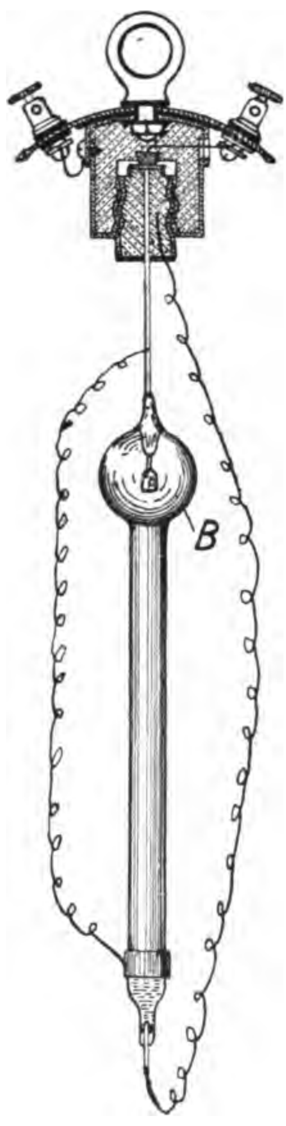


FIG. 219

that this total resistance of 1.6 ohm is not altered much by any increase or decrease in the arc resistance. Suppose the arc resistance to be doubled, this total resistance would only be increased to 1.7, and if the arc resistance were halved, the total would only alter from 1.5 to 1.55. When lamps are put in series on high pressures, extra resistances are not used, for the lamps act as resistances to each other.

A phenomenon in striking the arc was discovered by the author in constructing double arcs, that is, a double carbon lamp to burn two arcs in parallel. The experiment can best be shown by taking two arc lamps of any good make and coupling them on to a 60 or 65 volts circuit, with resistance to suit, as shown in Fig. 221. They will run perfectly in parallel; but couple the two positive carbons together by a wire *d*, and the whole arrangement is upset; and it will be found that when we close the switch to start the lamps it is impossible to get an arc struck on both lamps, only one of them can be lighted up. This is due to the fact that a spark is required to start the arc. When an arc is struck, the moment the carbons part a slight spark passes, due to the self-induction of the circuit, and this starts the action; but when we couple the two carbons direct, as at *d*, the two regulators do not act simultaneously: one draws apart a little before the other, and without a spark, for the self-induced current which would start the arc passes away through the connecting wire *d* and through the arc in the lagging lamp. The lamp which draws apart first cannot, therefore, start burning. Again, if we take wire *d* away and let the two lamps run as usual, and then reconnect at *d*, the lamps will not run perfectly; a see-saw will be set up between

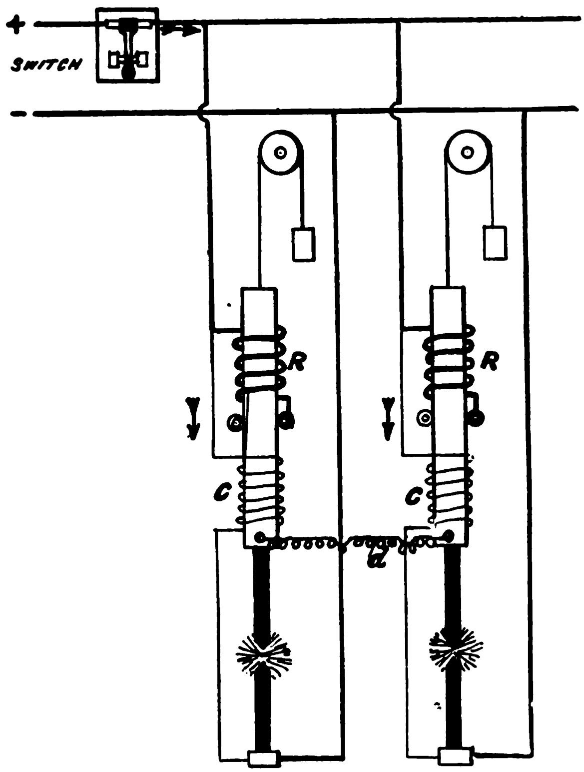


FIG. 221.—R. Kennedy's Arc Lamp Experiments

them, for any change in the counter-pressure or resistance of the one will affect the other, by a current passing along *d*.

Another point worthy of notice is that a lamp may start an arc beautifully with a new pair of carbon points, but will flicker and jump upon starting with an old pair. To show this properly, a lamp without a dash-pot, or one with its dash-pot removed for the experiment, is used. Put in a pair of new carbons and it lights up all right; let it burn for five minutes, then switch off and let it cool down; upon switching on again it will jump and flicker and splutter badly, the reason being that the points have become hardened, changed to plumbago-like carbon, which does not light up by the small spark. In time, however, the points will get hot and the carbon points worn down by the hammering action, and an arc will be struck. Again repeat the experiment, only, before relighting, file off the burnt ends, and the arc will start nicely without any trouble. Many arc regulators would require no dash-pot if it were not for this trouble in relighting old carbon points.

Finally, arc lighting is no doubt cheap and attractive, but the attendance required is much against its more general application. The enclosed lamp to some extent removes this drawback, but there seems room for a small arc taking 1 to 2 amperes, and running four or five in series on 200 and 250 volts. Twenty years ago a French inventor exhibited such a lamp with pretty effects at the Crystal Palace Exhibition. The current was 1 ampere alternating.

For lighting streets and large interiors the large arc lamp is quite correct, the only fault being the use of obscure globes—another case of unreasoning habit. At great expense a powerful light is produced, and then straightway an extinguisher is put upon it, extinguishing 60 per cent. of the expensive light. This procedure wants a lot of explanation to justify it. It is fashionable; that is all that can be said for it. The rational use of arc lamps would be a great benefit to the users of light and to the suppliers of current. Streets are by no means improved in lighting by large arcs far apart, and 25 to 30 feet high, with an obscure globe covering them. This practice is ridiculous, and should not be perpetuated. The competition of incandescent gas for street lighting is serious, for there is no objection to the products of combustion in a street, and the gas people don't place their lights under a bushel nor up in the sky, but in clear lanterns, and just where they can do most effective lighting.

The electrical engineers do not sufficiently study these details.

Inverted arcs for interior lighting are very effective where sufficiently large reflecting surfaces can be got and kept clean.

Photographic arc lamps are inverted, and the light reflected from a dead white surface for portraiture work. The figure shown

(Fig. 222) is a lamp made for photographic studios from designs by the author. The regulator is of the Pilsen type, shown in diagram, Fig. 212. A small enamelled bowl encloses the arc, and the light is thrown into the umbrella reflector, which is painted a dead white with a mix-

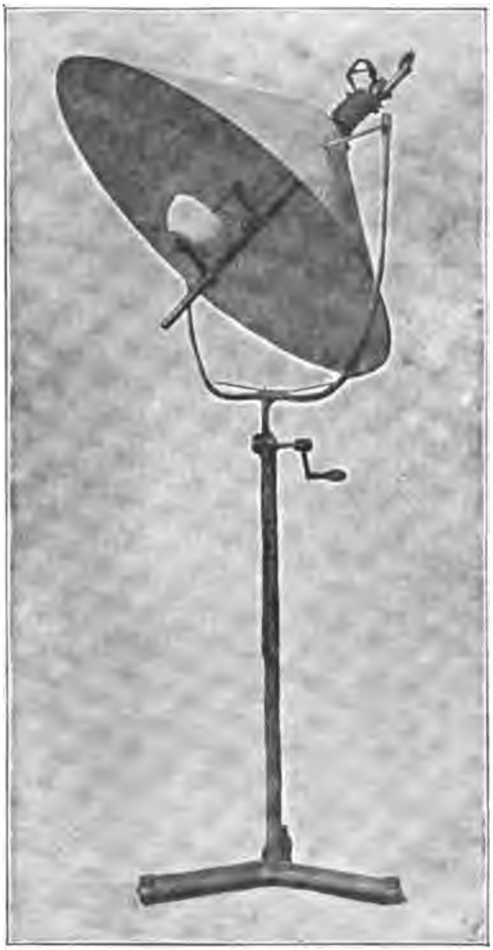


FIG. 222.—Photo-Electric Portraiture Lamp
(R. Kennedy's Designs)

ture of zinc white and colourless varnish. The other lamp (Fig. 223) is used for photo-zinco processes and photo-lithography, and also for blue printing engineers' and architects' plans. It is made with two, three, four, or five lamps, each of 30 to 50 amperes. The reflector is painted or whitewashed inside; the prints are stood in an easel in front, and very rapid work is made of them. The regulators are Pilsen type, and the lamps are put in series. Thus, on a 200 volt circuit four

lamps are put in series, and we get the full value of the current, for no resistances are required: thus we can get with 20 amperes and 200 volts four lights of nominally 2000 candle-power each, or 8000 candle-power for 4 units per hour, which at 4d. would run to 1s. 4d. per hour—a very cheap photographic light. On 500 volts we could use

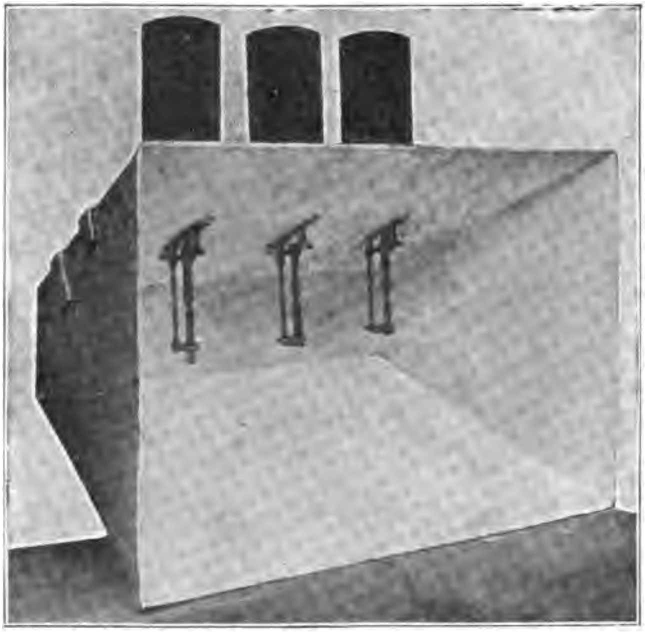


FIG. 223.—High-Power Photogravure Electric Lamp, Pilsen Regulators (Designed by the Author)

ten lamps in series, and so on. It is a mistake to use one big lamp; better results are got by using a series of smaller lights, as here shown, especially when a cheap supply of electricity at 200 to 250 volts is laid on.

Projector lamps, search-lights, biograph and lantern lamps are specially made either for hand feed or for automatic feed, and are made to work in any position. They shall be treated under ship and stage installations further on.

CHAPTER IX

PRACTICAL ELECTRICITY SUPPLY METERS

THE supply of electricity to consumers from central stations demands an accurate meter to total up the amount of electrical energy consumed in a given time, say per quarter or yearly, so that it may be correctly charged for against the customer. Electrical energy is sold by the Board of Trade unit, and that is a quantity of energy equal to 1000 watt hours, that is, 1000 watts for one hour, 500 watts for two hours, or one watt for 1000 hours. The watts multiplied by the time during which they are used give the units used. One unit would, as a rule, run a one brake-horse-power motor for one hour, allowing for all losses. It would therefore, roughly estimated, take 10 units to run a 10 horse-power motor, delivering 10 horse-power on the shaft to be driven. Hence a 10 horse motor would take in a working day of eight hours 80 units of energy; a 16 candle-power lamp takes about 60 watts of energy; hence a unit would run $\frac{1000}{60} = 16$ lamps for one hour.

To measure the consumpt, it is necessary to have a meter which runs at a rate proportional to the watts on the circuit at any moment. If one lamp is on, the rate of moving or indicating must be proportional to the 60 watts, and the index should record one unit consumed in a little less than 16 hours; if ten lamps were on the index would indicate one unit in 1.66 hours, and so on. The meter is, in fact, a calculating machine, which multiplies the watts by the time and adds them all up on the index, showing the watt hours consumed over a long period of variable supply.

Such a machine is necessarily a rather delicate piece of mechanism, requiring the highest skill in electro-magnetism, electric circuits, and mechanics in its design. A piece of mechanism capable of multiplying and adding and accurately entering up the result of complex values is no ordinary machine. In the previous chapter we dealt in the fundamental principles of the machinery of electricity meters; we must now take up the meters themselves as used in practice for closer examination.

One of the chief difficulties in the electric meter business has been the necessity for the measuring of very different forms of electrical energy. The supplies are given in two forms—continuous current and alternating current; and alternating currents are divided into two classes—those in non-inductive circuits and those in inductive

circuits. Some meters have been designed to measure any one of these currents, continuous, alternating non-inductive and inductive; others can only be used for continuous current alone; others, again, are suitable for non-inductive alternating circuits only; another class is fit for work on either non-inductive or inductive alternating circuits, and useless on continuous circuits. Another important point is that meters must be built to work with little or no appreciable waste of energy in themselves, and a third point is that they should register correctly on a small load and also on a high load.

These requirements constitute rather a large order upon the meter inventor, who has been rather apt to ignore them, with the result that at this moment there is not a meter known which entirely meets all of them in one machine.

Then, apart from these scientific questions before the electrical engineer, there are the questions of accuracy and durability of the vital parts in long-continued action. By this durability is not meant the mere mechanical wear and tear, but the permanently constant adjustment and action of the parts. For instance, some meters employ steel magnets—these may alter in time; and others employ commutators—these also may alter in time, their resistance changing.

As a rule, accuracy is not difficult to attain over a reasonable range; but at present there is an unreasonable demand for meters accurate down to 0.1 ampere on 200 to 250 volt circuits. And it may be supplied, but it cannot conduce to economy; for a meter moving under such small forces cannot be made accurate over any long range, and is pretty certain not to remain for long accurate on the higher loads, on which it is sure to register against the consumer. A meter registering on very small loads is, therefore, desirable for the suppliers, but is not likely to favour the man supplied. We now refer to two recent meters on electrolytic principles, in which some improvements overcame the original difficulties to a large extent; the first one obviates the weighing difficulty by using a fluid metal instead of a solid, and observing the volume of metal deposited instead of the weight. We have already alluded to an early attempt by M'Kenna in this direction. Theoretically the transfer of metal from an anode to a cathode of the same metal should not be opposed by any counter electric pressure; but in practice there is always some difference between the anode and the cathode. In the early zinc cells of Edison the counter-pressure was found to be as much as 0.0085 volts—quite an appreciable amount when the pressure at the terminals of the cell acting direct was only 0.01 volt; in fact, it amounted at low loads to 8.5 per cent. This counter-pressure is credited to the difference between the solutions in contact with the anode and cathode; but there is also the differ-

ence in resistance at the junction of the electrodes and the solution to contend with.

In the mercury electrolytic meter, by Mr. A. Wright, the back pressure is reduced to 0.0001 volt, using pure mercury and a solution of pure mercurous nitrate; and further, by placing the anode above

FIG. 224

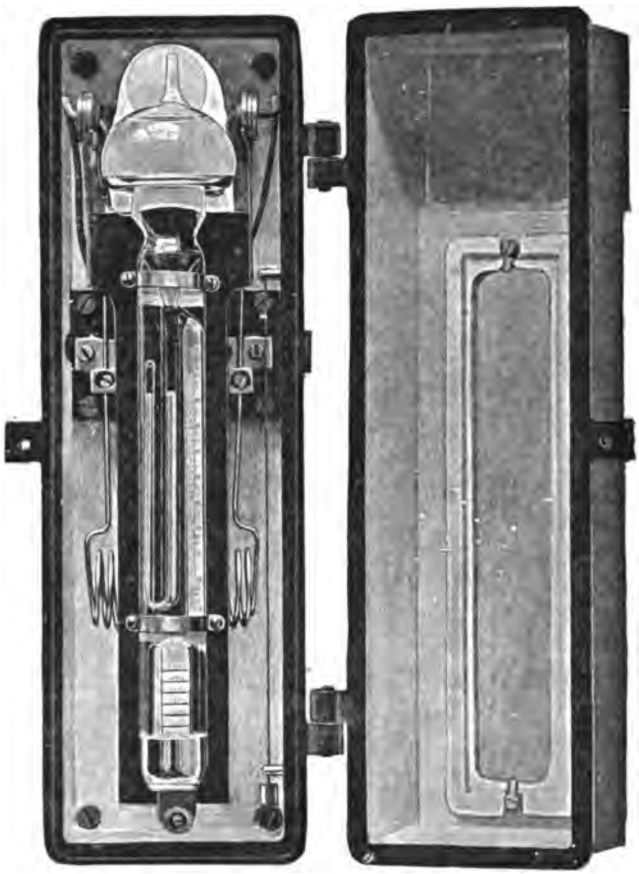


FIG. 225

Reason Manufacturing Company's Electrolytic Meter

the cathode, so that the dense solutions formed at the anode sink to take the place of the less dense solutions formed at the cathode; and still further, by maintaining a constant level of the anode surfaces.

Temperature errors are compensated for by using copper resistances. The rise in the copper resistance due to heat compensates for the fall in resistance in the cell due to same cause.

The level of the anode is maintained on the old bird-fountain system. There are two scales, as shown in Figs. 224 and 225.

The upper reads units and tens, the lower one hundreds. When the upper column rises to the top the syphon starts and empties it into

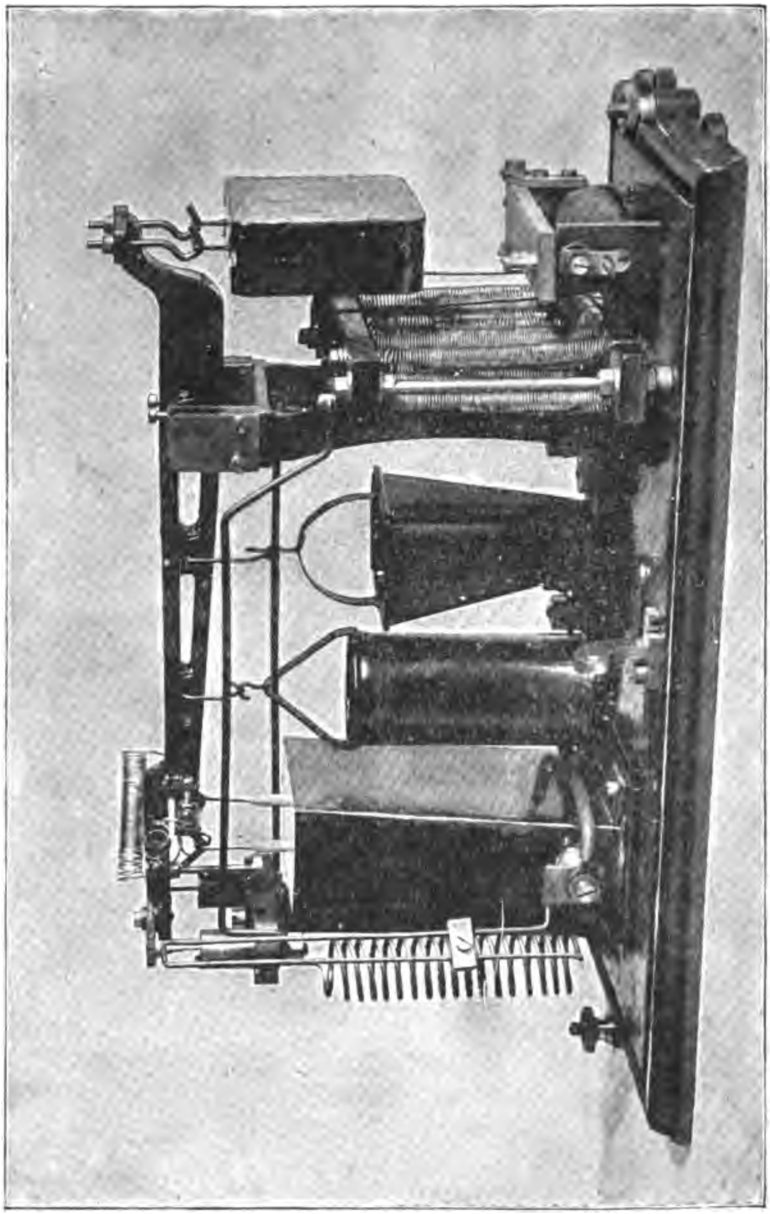


FIG. 226.—Long-Schattner Prepayment Electrolytic Meter

the lower, thus giving a range of readings calculated to cover a year's working on the capacity of the bird fountain. By tilting up the whole meter the mercury can be run back again. The results of

working are held to be entirely satisfactory. It is certainly well designed, and an electrolytic meter in which the vital details have been faced with scientific skill.

The next meter, the Long-Schattner, uses copper and copper sulphate like Edison's first meters. The principal novelty is the method of weighing out the units, which for simplicity is commendable.

The construction of the Long-Schattner prepayment meter will be best appreciated from the accompanying diagram of the instrument and connections (Fig. 227), and the complete view (Fig. 226).

In the diagram, A is a lever pivoted at X. At one end of the lever is suspended a copper plate B, which is immersed in a solution of copper sulphate contained in the box D, which is also of copper,

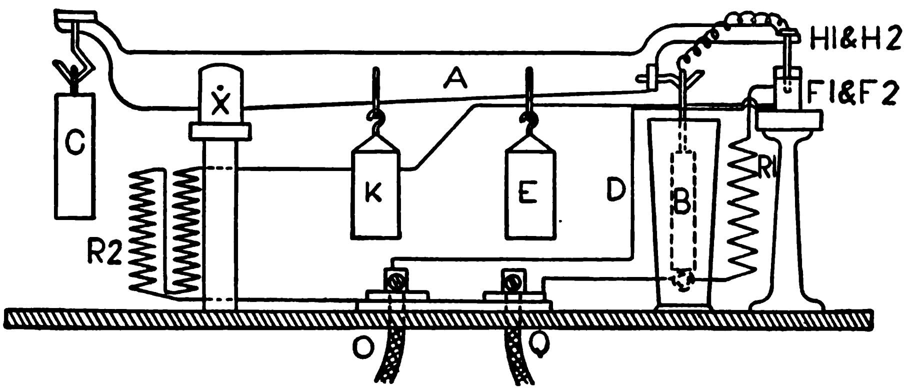


FIG. 227.—Long-Schattner Prepayment Electrolytic Meter

and forms the negative plate or cathode. C is a weight to balance the other side of the lever. K and E are cups to hold respectively the coins that come in through the slot and the standard weights with which the collector replaces the coins when he collects them, thus leaving the balance, or rather want of balance, unchanged. F1 and F2 are mercury cups; F1, the large one, is filled with mercury; F2, the small one, is half filled with mercury and then filled up with creosote oil. H1 and H2 are contact pieces forming a bridge across the mercury cups, which bridge is fixed on the lever. R1 is a main resistance, across which the depositing cell B D goes as a shunt, and R2 is a large resistance going from one mercury cup to the other.

Fig. 228 is necessary to explain the device mentioned in the above two figures as R2.

It will be seen that a single resistance across the mercury cups would not answer entirely satisfactorily, as with only one or two lamps the dimness produced would not be sufficient, or again, if it were made sufficient, the lamps would be practically extinguished if the full or nearly full complement of lamps happened to be on when the meter ran out its money.

Another point that has been suggested is, that with such an arrangement a customer with sufficient knowledge and want of

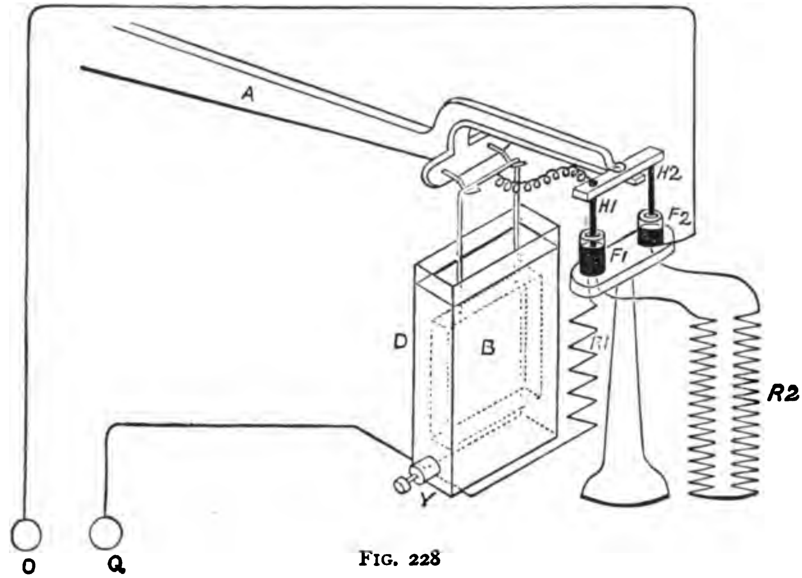


Fig. 228

principle might insert lamps of a low voltage, and thus continue using the current without inserting any coins. Of course, practically, that would not be possible, as the inspector, when he came round, would at once notice that the meter had been put "out of balance"; but the arrangement in Fig. 229 obviates both these difficulties.

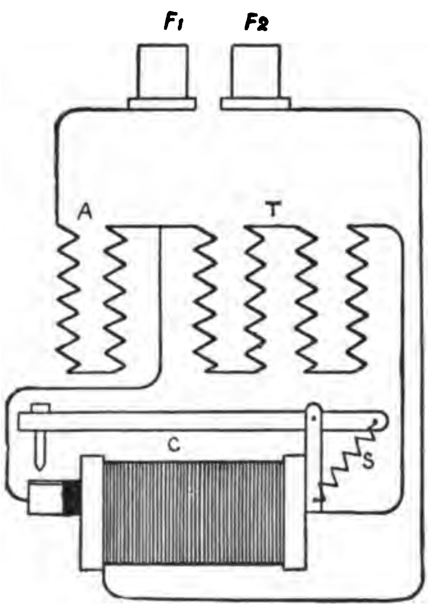


Fig. 229

A is a medium resistance, and T a high resistance; in series with these is the relay C. These three go in series across the mercury cups F 1 and F 2, and S is a spring acting against the armature of the relay. When the armature of the relay pulls up, the high resistance T is cut out.

The action is as follows: When the circuit is "broken" by the lever with only two or three lamps on, the high resistance is kept in series, thus causing proper dimness of the lamps, whilst with many lamps on when the "break" occurs the relay pulls up, cutting the high resistance T out of circuit. Thus always a proper dimness is obtained.

From the above the complete action may be gathered. To start with, the lever is up; a coin is inserted, bringing the lever down and establishing connection between the mercury cups, and it remains in this position until the anode B is lightened sufficiently to allow C to overbalance it, thus cutting off the current from the

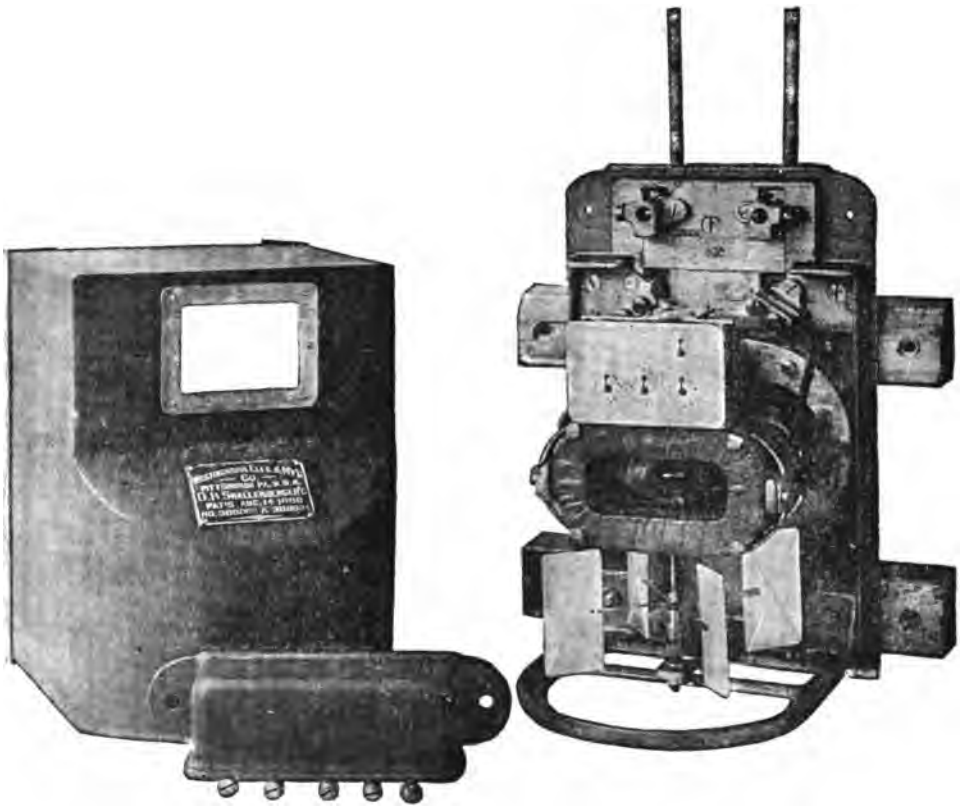


FIG. 230.—Westinghouse Meter with Cover off

main circuit and allowing only a current to light the lamps dimly until another coin is put in.

On the principles of the induction motor several successful meters are in the market.

The Westinghouse Company make an excellent alternating current meter for non-inductive circuits (Fig. 230), invented by Mr. Schallenberger. It consists essentially of a small induction alternating current motor working against a fan brake, hence dispenses with the troublesome commutator.

Description.—This meter is a direct reading instrument, recording the amount of current which has passed through it on the dial illustrated herein. The unit of measurement is the "ampere-hour."

Schallenberger Meter

The meter is designed to be connected directly in series with the lamps, and the entire current to be measured passes through a few turns of heavy wire, called the primary coil. Inside of this, and at an angle to it, is placed a closed copper coil, known as the secondary. Inside the secondary coil is a thin metallic disc mounted upon an upright spindle, which is connected at its upper end with a train of recording gears, and equipped near its lower extremity with a set of four aluminium fan blades (Fig. 231).

Fig. 231

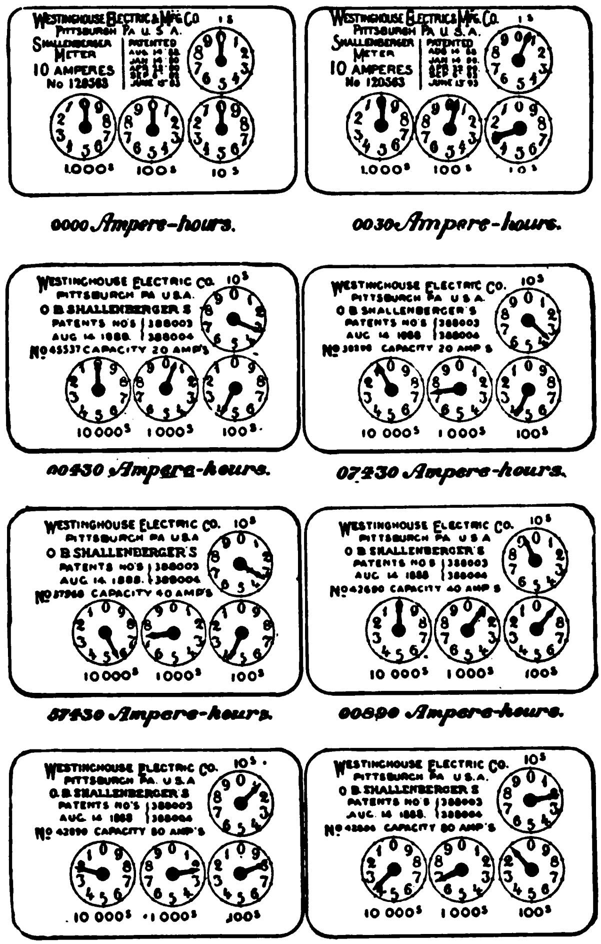
Fan-Brake of Westinghouse Meter

When an alternating current passes through the primary coil, an alternating field of force is developed in the direction of the axis of the primary coil. At the same time an alternating current is induced in the secondary closed copper coil, and this induced current develops another field of force in the direction of the axis of the secondary coil, that is to say, at an angle to the first. These two alternating fields of force combine to produce a resultant field; but as the alternations of the two are not coincident in time, the direction of the maximum effect of the resultant field is constantly shifting or moving in a circle, and what is termed a rotary field is produced. The metallic disc and its spindle tend to revolve in unison with the revolving field, but are retarded a certain amount by the fan blades, and as a result the speed of rotation is in exact proportion to the current passing through the instrument.

How to read the Meter.—All sizes of these meters are provided with four dials. On the 5 and 10 ampere instruments the dials are marked respectively 1's, 10's, 100's, and 1000's, while on all the larger sizes the dials are marked 10's, 100's, 1000's, and 10,000's. A complete revolution of any one index causes the index on the circle next higher in value to make one-tenth of a revolution; for example, one revolution of the "10's" dial denotes the passage of 100 ampere-hours, and this will be indicated by the index of the "100's" dial pointing to the figure 1.

When reading the instrument it is best to begin with the dial lowest in value. Failure to comply with this may lead to error, as it is clearly shown in dial No. 42690, which might be read 01890, while the correct reading is 00890, or 1000 less. A careful inspection would show that in order to read 1890, the index on the "1000's" dial would be nearer 2 than 1. This point is somewhat

exaggerated in dials Nos. 42890 and 42896. In the former case the possible reading is 22810, while the true reading is 21810, the reason being that the index of the "1000's" dial has been purposely slightly bent forward. A closer examination would show that, as the figure on the "100's" dial is clearly 8, the index on the "1000's" dial should be about completing a division, and, as it is nearer 2 than 3, it is evident that it must have been bent, and that 1 is the proper figure to read on the "1000's" dial. On dial 42896 the index has been bent backward, and a possible reading would be 35120, while the correct reading is 37120.



0000 *Ampere-hours.* 0030 *Ampere-hours.*

00430 *Ampere-hours.* 07430 *Ampere-hours.*

87430 *Ampere-hours.* 00890 *Ampere-hours.*

21810 *Ampere-hours.* 37120 *Ampere-hours.*

Reading Meter Dials

To tell the Exact Current flowing at any Time.—Note the number of revolutions made by the small "tell-tale" index on the top of the movement in a number of seconds equal to the constant of the meter. The number of revolutions noted will correspond to the number of amperes passing through the meter. For example, the 20 ampere meter constant is 63.3; if the index makes ten revolutions in 63.3 seconds, 10 amperes are passing through the meter. In order to avoid errors in reading, it is customary to take the number of revolutions in a longer time, say 120 seconds; then, as a formula, we have:—

$$\frac{\text{Number of revolutions} \times \text{meter constant}}{\text{Number of seconds}} = \text{Current.}$$

If, therefore, the index of a 20 ampere meter makes 19 revolutions in 120 seconds, the current passing is

$$\frac{19 \times 63.3}{120} = 10 \text{ amperes.}$$

Another meter on the same principles is made by Messrs. Siemens Brothers, with a magnetic brake, and is here illustrated. It is a motor generator practically, an alternating motor driving a short-circuited continuous current generator. It is shown in Fig. 232.

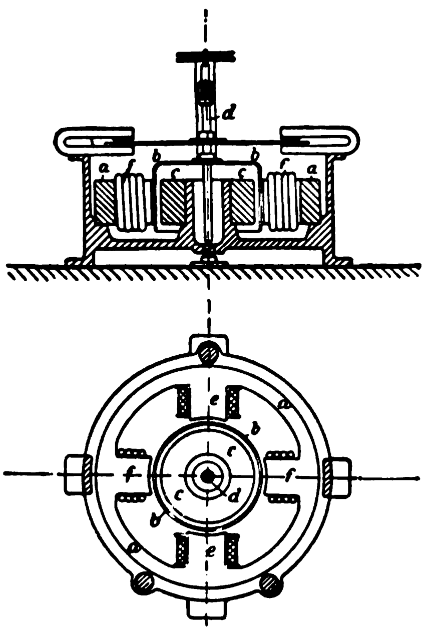


FIG. 232

Siemens Brothers' Alternating Meter

It consists of a simple motor on the Ferraris principle, combined with an eddy current brake, driving a counting train direct.

The moving part consists of a light pivoted aluminium drum *b*, surrounding a fixed iron core *c*, acted on by a rotating magnetic field produced by four poles *e e f f*, surrounding the drum. Two opposite poles of these, *f f*, are energised by the currents to be measured, and the other two, *e e*, by a current derived from the volt current, which has a phase displacement of 90 per cent. from the main current, produced by a combination of inductances and resistances.

In the current circuit (except for quite low ranges) a transformer is used in the same way as with the ammeters, only small leads are required from these to the instrument, as in the case of the shunts for direct current instruments. In the volt circuit a choking coil is used for the higher voltages.

These meters are unaffected by shock and vibration, and can be fixed to any wall.

Special means are taken to eliminate friction, so that the meter starts off at 0.25 per cent. of its full current, also will not continue to run without current even if the voltage is 20 per cent. above normal. Currents as low as 2 per cent. of the full load are registered with an accuracy within 3 per cent. The smallest variation of voltage is instantly recorded, and an over-load of 100 per cent. will not spoil the meter. They are calibrated to read direct in kilowatt-hours without a constant.

Alternating Motor-Generator Meter

Messrs. Chamberlain & Hookham's alternating current motor generator meter is also on this same induction principle. It is here illustrated in Figs. 233 and 234.

This meter (Fig. 234) consists of an aluminium disc A rotating upon a vertical spindle B, which runs in a jewelled bearing C. The disc A is driven by magnet D, wound upon which is a fine wire coil

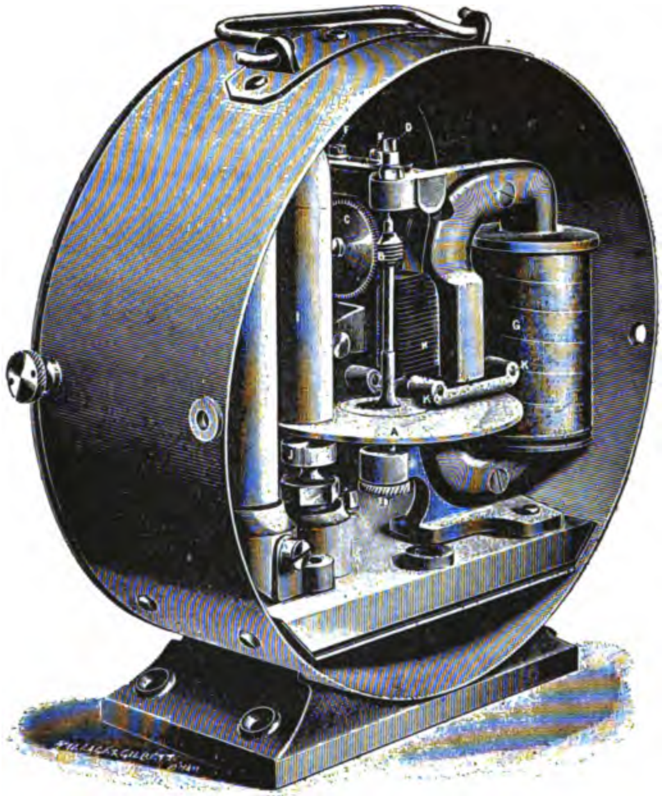


FIG. 233.—Chamberlain & Hookham Alternating Current Motor Meter

E, which is connected as a shunt across the mains, and gives a field varying with the E.M.F. Between the lower poles of the magnet D and the disc A are two flat spiral coils F F, which carry the current which it is desired to measure. The field produced by the coils F F and that produced by the coil E are out of phase, so producing a continuous rotation of the disc. The upper poles G G of the magnet D are adjustable, and either may be raised or lowered for the sake of correcting slight irregularities in the curve of the meter. A copper strip H (adjustable in relation to the poles G G) is fixed upon one of them to counteract any tendency to drive which might otherwise be produced by current in coil E alone.

The coils above described are connected to the circuit by three terminals marked S, M, and L. One end of coil E is connected through S to one of the main circuit wires, and its other end to terminal M. The other main wire is connected to terminal M, and

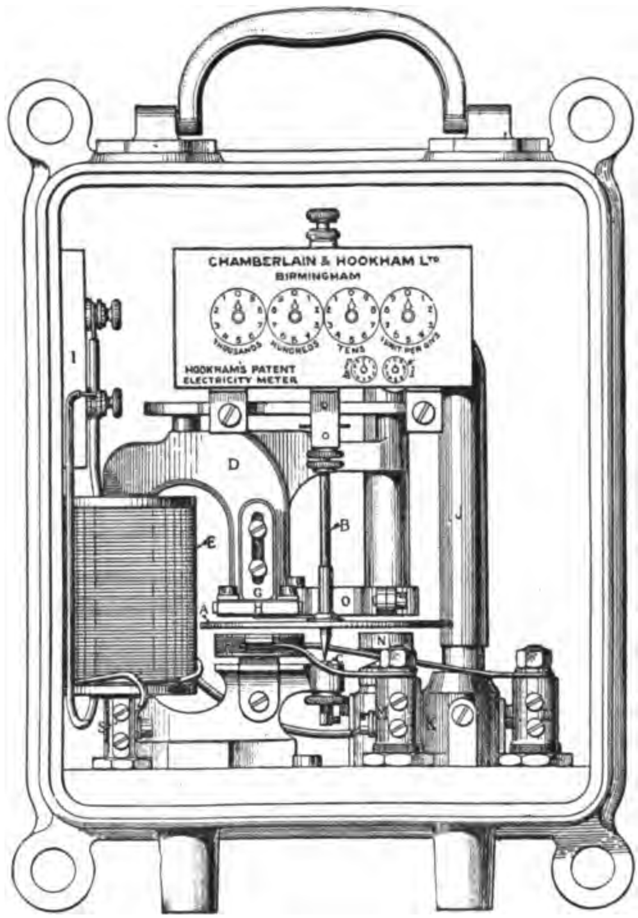


FIG. 234.—Chamberlain & Hookham Alternating Current Motor Meter

the wire carrying the current to the lamps is connected to terminal L. A fuse I is interposed in circuit of coil E.

The brake force of the meter is provided by a permanent magnet J, fixed in a cast-iron foot K, having an adjustable pole N. The position of the poles of this magnet can be adjusted so as to regulate the speed of the meter.

Upon the upper pole of the permanent magnet is fixed an iron arm O, carrying an iron plate P. The position of this plate P can be so adjusted as to greatly increase the correct range of the instrument without the use of any "starting force."

All parts of the meter are mounted upon a slate base, which is fixed inside the cast-iron box, and is itself further insulated from the box by means of ebonite bushes and supports.

Clock meters are of two kinds. First, those in which two clocks are used, in which the pendulums are acted upon by the current, one accelerated and the other slowed in proportion to the current and the difference registered by a differential gear and train. Dr. Aron's meter, by the General Electric Company, has long been known working on this principle; the illustration shows it in its latest form (Fig. 235).

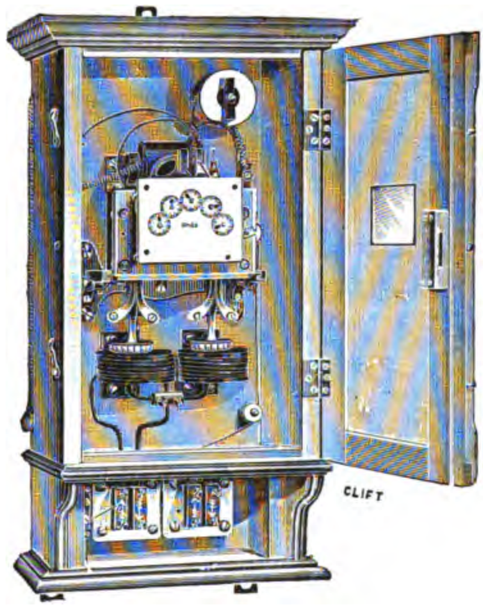


FIG. 235.—Aron Clock Meter

This meter is constructed on a well-known and thoroughly tried principle, viz. the influence of a current upon the swinging pendulum. In this meter both the pendulums are subject to the influence of the passing current, and the difference between the two is registered on the dial. It starts itself as soon as the necessary E.M.F. has been applied to the terminals. It has a synchronising gear, and measures correctly even when the two pendulums are not regulated and not in absolute synchronism. This method assures the greatest possible sensitiveness to any change in the consumption of the current and accuracy of registration.

The Aron meter consists essentially of two pendulum clocks which are synchronised so as to keep the same time while no electricity is recorded.

In the old type meter the pendulums were long, and the bob of one was replaced by a solenoid of fine wire swinging symmetrically above a stationary coil of thick wire.

By means of such an apparatus the electric energy given to a circuit can be recorded by connecting the pendulum solenoid as a shunt with the circuit, and at the same time passing the main current through the stationary coil.

The mutual action of the two currents is to exert a force which will act on the pendulum either in the same direction or in the opposite direction of gravity. In the first case the clock which is affected by the current will gain, and in the second case it will lose;

but in both cases the force will be proportional to the watts absorbed by the circuit.

Let T_1 be the time in seconds of one beat of the pendulum of either clock when no current is passing, then

$$T_2 = \frac{K}{\sqrt{g}} \text{ seconds}$$

where K is a constant which depends on the shape of the pendulum and g is the acceleration of gravity. Let λ be the acceleration due to the inter-action of the two currents, then the time of a beat of the pendulum which is affected by the currents will be

$$T_2 = \frac{K}{\sqrt{g \pm \lambda}} \text{ seconds,}$$

$+\lambda$ when the pendulum is accelerated, and $-\lambda$ when it is retarded.

Let the number of beats per second of the two pendulums be n_1 and n_2 respectively, then

$$n_2 - n_1 = \frac{1}{T_2} - \frac{1}{T_1} = \frac{1}{K}[\sqrt{g \pm \lambda} - \sqrt{g}] = \frac{\sqrt{g}}{K}\left[\sqrt{1 \pm \frac{\lambda}{g}} - 1\right] =$$

$$\frac{\sqrt{g}}{K}\left[\pm \frac{\lambda}{2g} - \frac{1}{8}\left(\frac{\lambda}{g}\right) \pm \frac{1}{16}\left(\frac{\lambda}{g}\right)^3 \ . \ . \ .\right].$$

Or when $\frac{\lambda}{g}$ is sufficiently small we shall have

$$n_2 - n_1 = \pm \frac{\sqrt{g}}{K} \times \frac{\lambda}{2g};$$

but as λ is proportional to the watts, W, absorbed by the circuit, we have

$$n_2 - n_1 = u\ W \rightarrow$$

when the pendulum is accelerated, or

$$n_1 - n_2 = u\ W \rightarrow$$

when the pendulum is retarded, u being a constant.

In both cases the number of joules absorbed by the circuit during any interval of time will be proportional to the number of beats gained or lost during that time by the pendulum which is affected by the current.

The New Type Aron Meter.—The new instrument is essentially of the same principle as the old type meter just described, that is to say, the influence of the current on the swinging pendulum is recorded. The old type meter had the disadvantage that too much clockwork was used and depended on for accuracy: the clocks had to be wound up once a month; they had to be regulated; the pendulums had to be put in motion to start the clocks. All these disadvantages are now entirely avoided, and the meters are portable.

Clock Meters, Theory of

The principal difference between the new type meter and the old type is, that it is wound up electrically; it has very short pendulums, and therefore is portable without the necessity of clamping the pendulums. It will start of itself when the necessary difference of potential is applied between the terminals. The bobs of both pendulums are replaced by solenoids, and they are therefore both subject to the influence of the current, the one being accelerated and the other retarded. The sensitiveness of the meter is thus increased, and the effect of external magnetism is neutralised. The pendulums are about 5 inches long, and each makes about 12,000 beats per hour on no load. They are so sensitive under the influence of the current that they together show a difference at full load of about 3000 beats per hour.

With so large a difference of the period of the pendulums the quadratic term $\left(\frac{\lambda}{g}\right)^2$ could not be neglected, and the constant of the meter would, therefore, not be the same throughout the range. The difference of amplitude of the two short pendulums will also introduce a considerable error. These errors are, however, eliminated by reversing the direction of the current in the pendulums every ten minutes, and at the same time also reversing the motion work in such a manner that the instrument continues to register in the same direction. By this contrivance the pendulum, which formerly was accelerated, will be retarded, and *vice versa.*

During the first half part of a cycle of the reversing gear the number of beats gained by the accelerated pendulum will be

$$\frac{1}{K}[\sqrt{g+\lambda_1} - \sqrt{g}] \text{ per second,}$$

and the retarded pendulum will lose

$$\frac{1}{K}[\sqrt{g} - \sqrt{g-\lambda_2}] \rightarrow \text{ beats per second.}$$

Therefore the meter will register

$$\frac{1}{K}[\sqrt{g+\lambda_1} - \sqrt{g-\lambda_2}] = \frac{\sqrt{g}}{K}\left[\frac{\lambda_1+\lambda_2}{2g} - \frac{1}{8}\left\{\left(\frac{\lambda_1}{g}\right)^2 - \left(\frac{\lambda_2}{g}\right)^2\right\}\right] \text{ beats per second.}$$

During the second part of the cycle the accelerated pendulum will gain

$$\frac{1}{K}[\sqrt{g+\lambda_2} - \sqrt{g}] \rightarrow \text{ beats per second,}$$

and the retarded pendulum will lose

$$\frac{1}{K}[\sqrt{g} - \sqrt{g-\lambda_1}] \rightarrow \text{ beats per second.}$$

Hence during this period the meter will register

$$\frac{1}{K}[\sqrt{g}+\lambda_2 - \sqrt{g}-\lambda_1] = \frac{\sqrt{g}}{K}\left[\frac{\lambda_1+\lambda_2}{2g} + \frac{1}{8}\left\{\left(\frac{\lambda_1}{g}\right)^2 - \left(\frac{\lambda_2}{g}\right)^2\right\}\right] \text{ beats per second}$$

Therefore, during a cycle of the reversing gear, the meter will register on an average

$$\frac{\sqrt{g}}{2\,K}\left[\frac{\lambda_1+\lambda_2}{2g}+\frac{\lambda_1+\lambda_2}{2g}\right]=\frac{\sqrt{g}}{K}\times\frac{\lambda_1+\lambda_2}{2g}\text{ beats per second.}$$

But as both λ_1 and λ_2 are proportional to the watts absorbed by the circuit, the registration of the meter will be proportional to the joules absorbed during any multiple of the time required to complete one cycle of the reversing gear.

The Clockwork.—The driving power of the winding gear is transmitted to the two clocks through arbor K, Figs. 236 and 237, on which is fixed a shaft, carrying the loosely mounted planet wheel, b^2.

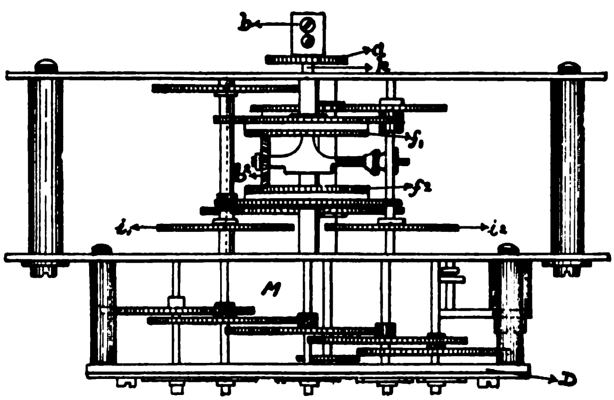


Fig. 236

Two crown wheels, f^1 f^2, loosely mounted on K are in gear with b^2, from which they receive motion. Each crown wheel is geared with a clock train, having an escapement and a pendulum. Thus f^1 is geared with escapement i^1, and f^2 with i^2.

One other end of the two clock trains are geared with a differential gear, mounted on arbor q, and which is similar to the one on arbor K. The two crown wheels v^1 and v^2 turn in opposite directions, and thereby turn planet wheel q^1.

When the two pendulums beat normal time, then v^1 and v^2 will rotate at the same rate, and arbor q will not be turned. But if, for instance, pendulum p^1 is accelerated and gains N^1 beats per second, and p^2 is retarded and loses N^2 beats per second, then the speed of v^1 will be increased, and that of v^2 will be diminished amounts, which are proportional to N^1 and N^2 respectively; hence the arbor q will be turned with an angular velocity which is proportional to N^1+N^2. As arbor q is geared with the motion work M, the registration on the dial D will be proportional to N_1+N_2.

The Reversing Apparatus.—The next part of the meter to be described has for its object the elimination of the errors due to mechanical and electro-magnetic deviations of the pendulums. This is effected, as already mentioned, by reversing the pendulum current every ten minutes, and at the same time reversing the connection

between the clocks and the motion work. The apparatus is shown in Figs. 236, 237, 238, and 239.

Between arbors k and z (Fig. 238) is a third one, not shown,

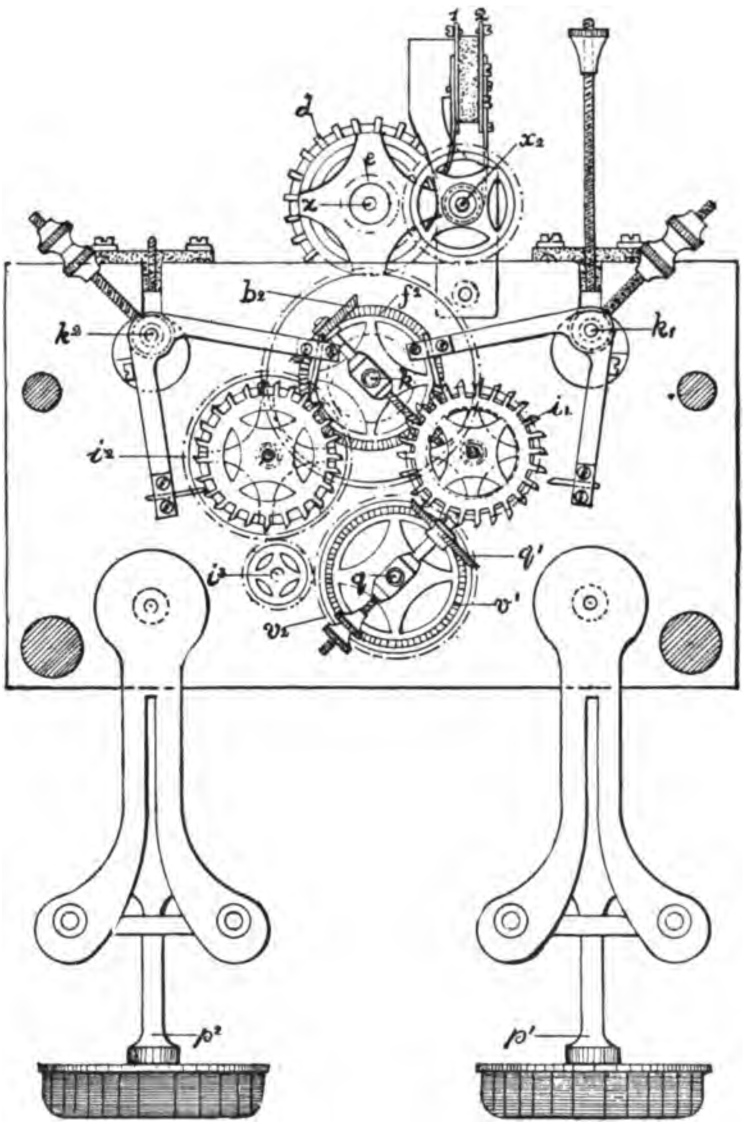


Fig. 237

which carries a wheel and a pinion. The former is in gear with wheel a, and the latter with wheel d, which is loosely mounted on arbor z. Wheel k^3 is fixed on z and gears into wheel, which, together with the commutator, are fixed on arbor x^1.

The wheel *d* carries a crank m^1, to which is attached the one end of the watch-spring *r;* the barrel *e* of this spring is fixed on *z*.

The wheel *d* is revolved through the motion of arbor *k*, and causes the crank m^1 to wind up spring *r*, which is released three times during each revolution of *d*, the time between two consecutive releases being ten minutes. Every time the spring is released the arbor *z* is turned through one-third of a revolution, and arbor x^2, with the commutator, is turned through one-half of a revolution.

There are four brushes, 1, 2, 3, and 4, in contact with the commutator, of which 2 and 3 are connected with the pendulum wires, and 1 and 4 to the shunt terminals of the meter.

In the position of the commutator shown in Fig. 238, the current goes from 4 to 3; then through the pendulum solenoids, back to 2; then to 1, and thence to the shunt terminal. In the second position of the commutator the shunt will go from 4 to 2; then through the pendulum solenoids to 3, and thence to 1. The direction of the current through the pendulum circuit in the two positions of the commutator are, therefore, opposite.

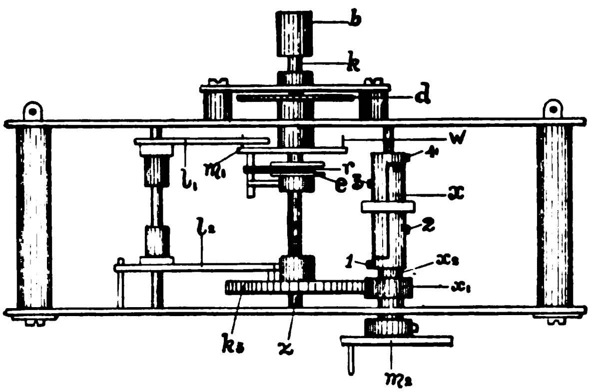


Fig. 238

The release of the spring *r* is effected in the following way: On the circumference of crank m^1 are fixed three equidistant pins *w*, each of which will, when it is in the right position, lift lever l_1. Lever l_2, which locks arbor *z*, and which is attached to the same arbor as l_1, will therefore also be lifted. Arbor *z* will thus be unlocked and spring *r* will be released.

The mechanism for reversing the connection between the clocks and the motion work is shown in Figs. 238 and 239. FF_1 is a lever with fulcrum at z_1. Spindles *g* and *g* are fixed on the ends of this lever.

These spindles carry the two loosely mounted wheels E and E_1. On the bent end F of the lever are fixed two thin flat springs *r* and r^2, between which the pin of the crank m_2 slides. In the position of the crank m_2, shown in Fig. 239, the crank-pin will be pressed against spring r^2, and the wheel E will gear into wheel S_1.

At the next release of the watch-spring *r*, the arbor x^2 will turn through half of a revolution and, therefore, the position of the crank-pin will be diametrically opposite to that shown in Fig. 239. During

this motion the crank-pin will press against spring r^1, and will throw lever F F^1 over so as to cause wheel E to gear into wheel S, and at the same time the two wheels E^1 and S^1 will be brought out of gear. The angular motion of lever F F^1 is controlled by two stop-pins, t and t^1.

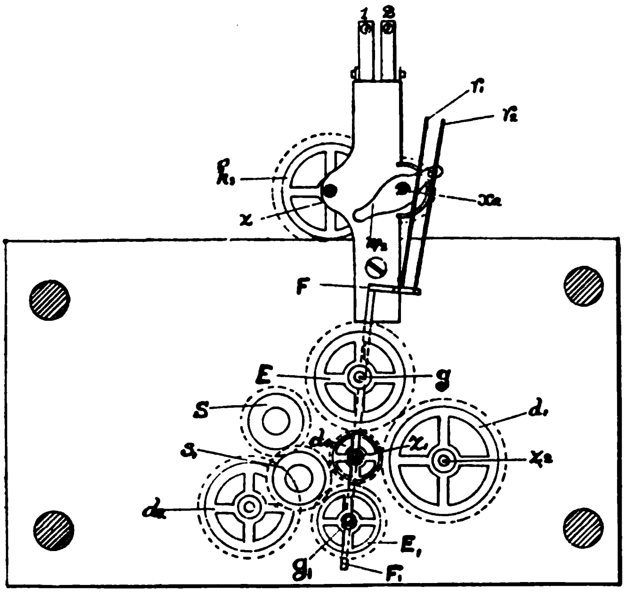


FIG. 239

The small wheel d^4 is loosely mounted on arbor z^1, about which lever F F^1 turns. The wheel d^4 is always in gear with wheels E E^1 and d^1.

The wheel d^2 is fixed on arbor q (Fig. 237), of the second differential gear, and works into a pinion on the arbor of wheel S_1.

The wheel d^1 is the first wheel of the motion work, and it will now be seen that it will continue to turn in the same direction even if the direction in which wheel d^2 turns be changed, provided that lever F F^1 is thrown over at the same moment. This is, of course, effected by the commutator and the crank m_2 being fixed on the same arbor, x^2.

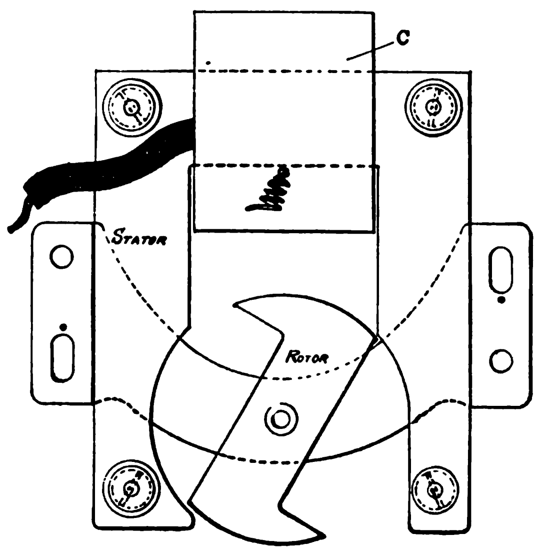


FIG. 240

The Winding Gear.—The apparatus which winds up the clocks consists of a single horse-shoe field-magnet (stator), with one exciting coil, C, fixed on the yoke (Fig. 240). In the gap between the pole-pieces of the stator is an oscillating armature (rotor), consisting of a shaped unwound iron core (Fig. 241), which is only allowed to

turn through an angle of about 75 degrees, and which is mounted loosely on a spindle.

When the stator is excited it attracts the rotor, and in order to prevent attraction in the opposite direction the trailing horn of the right-hand pole-piece of the stator is cut off. The spindle about which the rotor turns is directly connected with the arbor which drives the two clocks.

The exciting current is only kept on for a fraction of a second—just long enough to cause the rotor to turn through an angle of 75 degrees. The object of this operation is to put tension on the power-spring.

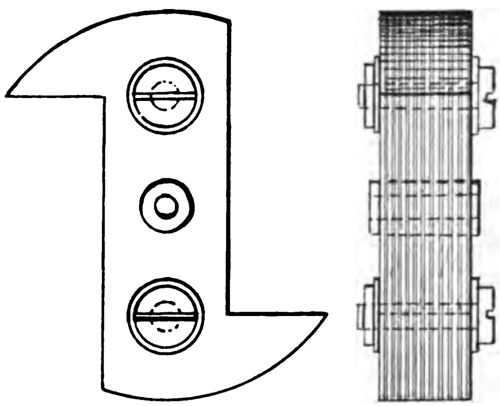


FIG. 241

During the fraction of a second, while the rotor winds up the spring, the clocks are driven by the spiral spring, which also makes a flexible connection between spindle and arbor.

The electric circuit is closed and opened by a circuit-breaker, which consists of a forked switch with two prongs. The former is a nickel plate and the latter is made of stabilite, with a small nickel plate attached to it for the silver contact-pin to rub on when the circuit is open. The middle part of the switch is made of brass, and is fixed on the spindle about which the switch turns. The contact-pin is attached to the rotor, and during the winding up it will press against the prong and thus turn the switch, the pressure being supplied by spiral spring.

The stator and rotor of alternating-current winding-gears are built up of thin soft-iron laminæ, which are insulated from each other. In continuous-current winding-gears the laminæ are about twice as thick as those used for alternating currents.

Double Dial Battery Meter.—For the purpose of recording the energy put into and taken out of a battery of accumulators, two meters might be used—the one to be inserted in the charging circuit and the other one to be connected up on the circuit from the accumulators. But in order to avoid the expense and the trouble of the two meters, one Aron meter with a specially designed clockwork will suffice.

It is evident that such a meter must have two dials—one for registering the energy put into the cells and the other to record the energy taken out of the cells.

With the exception of the clockwork just described, the double dial battery meter is in every respect identical with the standard type of Aron meter.

The Aron-Miller Battery Meter.—This type of Aron meter has one large dial, 4 inches in diameter, and one pointer of corresponding length (Fig. 242). The division on the dial may either indicate B.O.T. units or ampere-hours at a given constant difference of potential between the terminals of the pendulum circuit.

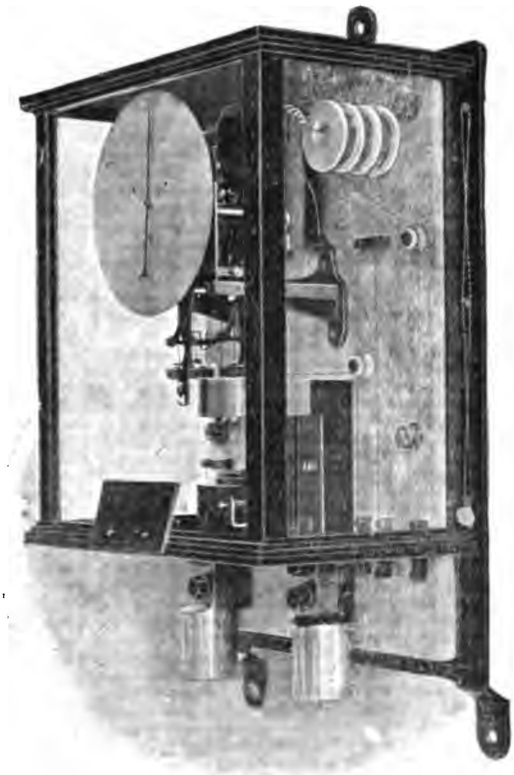


Fig. 242.—Aron-Miller Battery Meter

The pointer moves clockwise during the time the battery is being discharged, and anti-clockwise while the battery is being recharged.

The two pendulum solenoids, together with two resistances, R_1 and R_2 (Fig. 243), form the pendulum or shunt circuit.

The meter is fitted with a relay, R, which is actuated by the main current and which short-circuits the resistance R_1 during the discharge of the battery, and the pointer will then indicate on the dial the exact number of B.O.T. units or ampere-hours which have been given off by the battery.

When the battery is being charged the resistance R_1 forms part of the resistance of the pendulum-circuit, and, therefore, the current in this circuit is less than when the battery is discharging; consequently, a greater amount of electric energy or electric quantity, as the case may be, is required to make the pointer return through the same number of divisions. The meter is, therefore, "slow on charge."

If it is required to give the battery *n* per cent. excess of charge over that of discharge, then R_1 must be *n* per cent. of the resistance of the remainder of the pendulum circuit.

The relay consists of a permanent magnetic needle, which can turn about a horizontal axis.

The natural position is parallel to the direction in which the current flows through the ampere coils of the meter.

When the current flows towards the battery (charge) the magnet will try to place itself at right-angles to the direction of the current, and in doing so it short-circuits the resistance R_1. When the current is flowing in the opposite direction (discharge) the magnet is prevented from turning by a stop-pin.

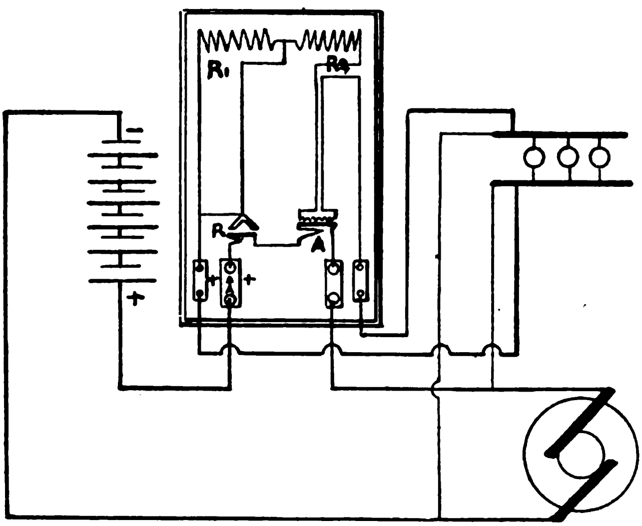


Fig. 243

With the exception of the relay and the large dial, the construction of this type of the Aron meter is identically the same as that of the standard type, the pointer being fixed on the arbor of the usual fourth dial.

The other type of clock meter is that known as the feeler type, in which a pendulum or balance vibrates at a constant rate, and periodically moves the first wheel of a recording train through a portion of a revolution proportional to the current at any moment.

They are characterised by considerable complications, but are, as a rule, accurate and reliable.

The pendulum is preferably electrical driven, and the measuring device may be a watt-meter or an ammeter.

We may notice the meters of Lord Kelvin, Siemens Brothers, and Messrs. Johnson & Phillips in this class.

Siemens Brothers' meter on the clock principle is very simple; it has a balance-wheel operated by a magnet and a moving coil ammeter. The foregoing meters, Aron, Kelvin, and Johnson and Phillips, can be used for both alternating and continuous currents; this one is designed for continuous current only. It is shown in Fig. 244.

The instrument consists of a moving coil instrument reading amperes or watts direct, in conjunction with a registering mechanism driven by electricity, which actuates a counting train at intervals of about $3\frac{3}{4}$ secs. and propels it an amount corresponding to the deflection of the ammeter or watt-meter.

In the case of the ampere-hour meter, the ammeter part of the instrument is of the usual moving coil permanent magnet type. In the watt-meters, however, the field is produced by an electro-magnet, the coils of which are included in the volt circuit. In this case there

is a contact worked by the clock mechanism which momentarily short circuits the coils of the electro-magnet just before the counting train is actuated, in order that the reading registered shall be that corresponding to a point on the rising part of the magnetisation curve of the iron, so that errors due to hysteresis, which would otherwise occur through readings being taken sometimes on a rising and sometimes on a falling voltage, are obviated.

A separate scale and pointer are provided for the ammeter or watt-meter, so that amperes or watts can be read off at any time, saving the use of a separate instrument

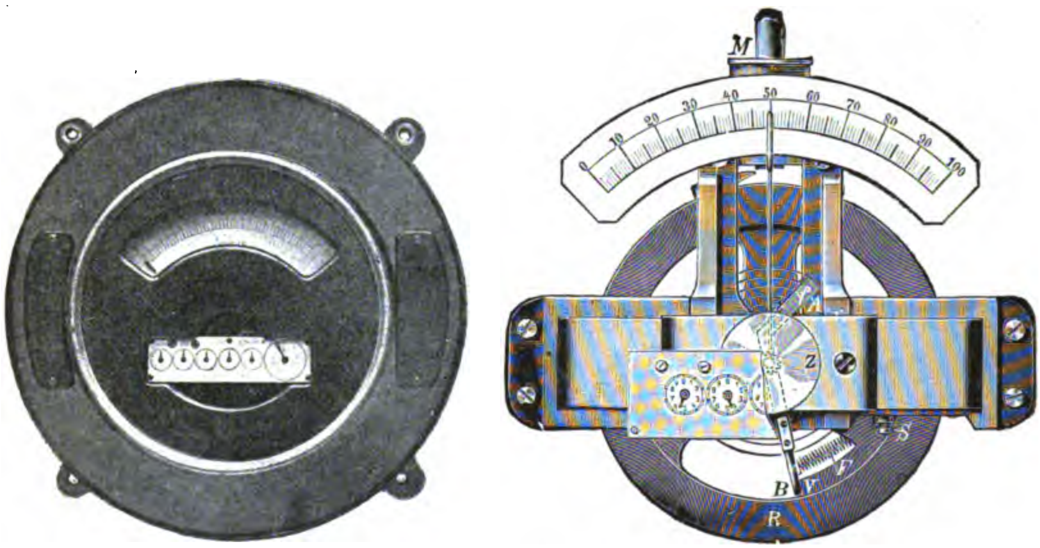


FIG. 244.—Siemens Brothers' Feeler Meter

The clock mechanism consists of a heavy balance-wheel R, delicately poised on the ball bearings, which receives occasional impulses from an electro-magnet M connected with the volt circuit, and will maintain a constant speed spite of large variations of voltage as much as 15 per cent. in either direction.

The counting train is worked by a disc Z, with a serrated edge, over which is a small spring continually moving backwards and forwards, driven by the balance-wheel; while moving in one direction this spring just does not touch the disc, but at some point in its return journey meets a projection on the pointer of the ammeter (or watt-meter), which causes it to engage with the disc and propel it through an angle corresponding to the deflection of the pointer; at the same time the pointer is carried back to zero, where the disc is freed again. These operations are carried out at every swing of the balance, so that readings are taken every $3\frac{3}{4}$ secs. and added up by the counting mechanism. We can see at a glance that the clock is working properly by the motion of the pointer, which moves to and fro between the zero and the reading corre-

sponding to the amperes or watts flowing in the circuit. These meters can be affixed to any wall, and do not require to be levelled up, nor will they be affected by vibration.

For use on tramcars or railways, they are strongly recommended. For this purpose a special form of hanging is supplied with two pairs of springs, with or without a wooden case to also contain the shunt when necessary. For tramway and other work where the current is often broken, it is necessary to connect the volt circuit of the meter, so that it is not broken with the current, in order to avoid frequent stopping of the clock.

Lord Kelvin's meter is shown in Fig. 245, open. This meter was introduced in 1892, to meet the demand for an accurate meter for the measurement of electricity supply. This form consisted of a self-winding clock arranged in combination with an electro-magnetic system to record at periodic intervals the vertical displacements of a small rod, these displacements being exactly proportional to the current passing through the main solenoid to the lamps.

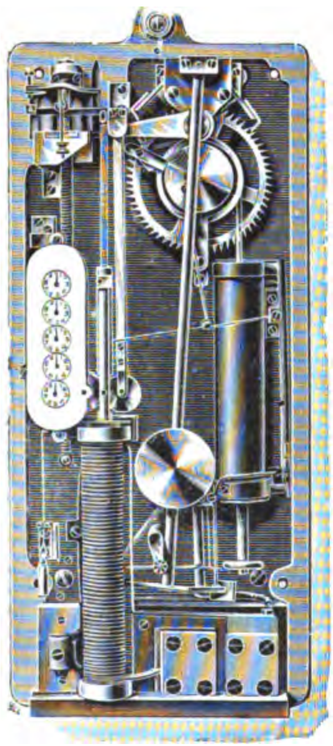


FIG. 245.
Lord Kelvin's Electricity Meter

Since the introduction of this meter many improvements have been introduced, principally in the driving mechanism, with the result that it has been greatly simplified, and a thoroughly reliable meter produced. This meter is shown in Fig. 245. The electrical part consists of a main solenoid, which carries the current to be measured. Into this is entered a long, thin plunger of very soft iron suspended from a specially prepared spiral spring. The upper end of this spring is supported on one end of the beam of a small balance, which is adjusted in connection with the spring to allow the plunger to be pulled down by an amount almost exactly proportional to the current passing in the main solenoid. The plunger is guided at the top and bottom, so that it passes between two flat rollers. One of these is geared to the recording dials and the other is on the end of a lever. At periodic intervals of about one minute this lever is moved by a revolving cam, causing the plunger to be pressed against the two rollers. Immediately following this motion, a lifter acted on by a crank begins to rise, lifting the plunger to its zero position and making a record on the counter in proportion to the

current passing in the coil. The zero position of the plunger is adjusted so that the lifting bar touches a fixed stop and the disc on the plunger at the same time. The driving mechanism is exceedingly simple, and entirely automatic in its action. It consists of a drum and scape-wheel on the same spindle, caused to revolve by means of a small cylindrical iron weight. This weight is connected to an arm carrying an eccentric quadrant of steel, which grips against the drum when the weight is going down. When the weight has fallen to nearly the bottom of its range, it presses down a contact, sending a current through a solenoid into which the upper end of the weight is entered, causing the weight to be raised and breaking the contact again. The speed of rotation is regulated by means of a pendulum, and is quite uniform and independent of the current passing in the main coil.

Messrs. Johnson & Phillips' meter (Figs. 247 and 248) is also on the clock principle of the feeler type, with an electrically-driven pendulum.

This meter is constructed on the integrating principle, the integrations being made at intervals of thirty seconds.

It may be divided into three chief parts :—

1. A time-keeping mechanism in the form of an electrically-operated pendulum.
2. A current or energy measurer in the form of an ammeter.
3. Integrating mechanism, including the counter showing units.

The mechanism of this part consists of a pendulum rod of aluminium suspended on a pivoted spindle, and having a lead bob at its lower end. This pendulum normally beats half seconds, and the lead bob can be raised or lowered for the purpose of regulation.

The armature of an electro-magnet operates the pendulum by means of a pin working against a roller, giving it an impulse whenever current passes through the electro-magnet. By means of an intermittent contact action the pendulum only receives an impulse when the amplitude of its swing has fallen below a certain limit. About half-way down the pendulum rod a steel toggle is pivoted to hang quite freely. As the pendulum oscillates, this toggle sweeps over a block on the upper one of two contact springs. The block has a groove cut across it with which the point of toggle engages when the swing of the pendulum is not sufficient to carry the toggle clear of the block. As the pendulum swings back the toggle point slides along the face of the block, catches in the groove, and thus presses down the upper spring into contact with the lower one. A current then passes through the electro-magnet, causing the armature to give the pendulum an impulse. This impulse is sufficient to increase the amplitude of the pendulum movement so that it swings several times to and fro before the arc of oscillation is reduced sufficiently

for the toggle to again slide back and engage in the groove on block. With this form of contact a variation of 10 or 20 per cent. in the driving current will not cause any material variation in the rate of the pendulum. When the circuit is broken things are so

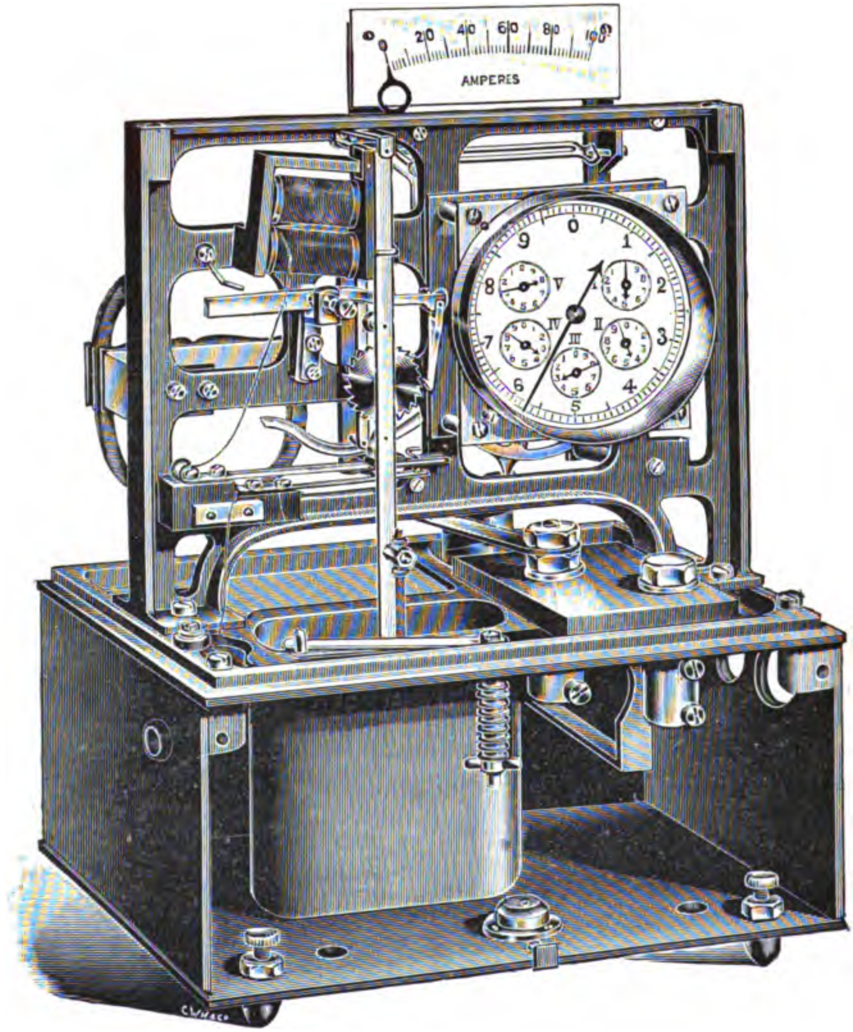


Fig. 246.—Johnson & Phillips' Meter (Front View)

adjusted that the pendulum comes to rest with the toggle in the groove on the block, and the contact closed. The pendulum will thus receive an impulse and start swinging directly the circuit is completed.

The swinging of the pendulum operates a rocking lever by means of a roller fixed to the pendulum rod. This lever in its turn actuates a ratchet wheel, moving it one tooth every complete swing; as there are thirty teeth in this wheel, it follows that it, together with its spindle, make one complete revolution in thirty

seconds. Attached to the other end of this ratchet-wheel spindle is a crank which operates the integrating mechanism

The current or energy measurer takes the form of an ammeter, which consists of a light aluminium hand fixed to a steel spindle.

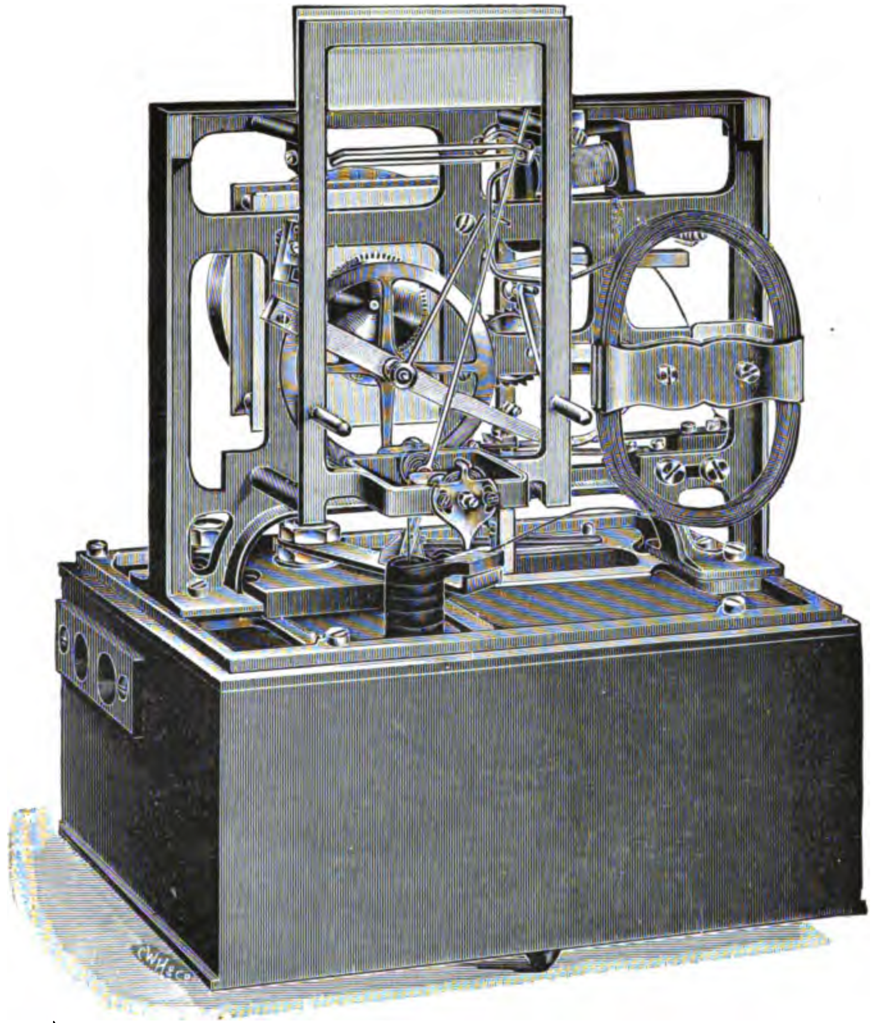


FIG. 247.—Johnson & Phillips' Meter (Back View)

The spindle also carries an aluminium cross-bar or beam set at right angles to the hand, and two phosphor bronze coiled springs.

The collets of these springs are firmly fixed to the spindle, and the spindle is mounted in jewelled screws. From one end of the cross-bar or beam an iron wire is suspended entering into a solenoid, through which the current to be measured flows. This iron wire is drawn into the solenoid against the tension of the two springs.

The Integrating Mechanism.—This consists of a rocking lever

pivoted, and carrying a pawl acting on a wheel (which may be considered as the first wheel of the counting train). The lever is weighted so that it falls by gravity; the other end of the lever is curved and is acted on by the pin in the crank, which, as it revolves under the action of the pendulum, rocks the lever up and down once every half minute.

Fixed to the boss of the lever is a rod bent at right angles at its upper end, so as to rest against the hand of the ammeter. In order that the hand may not be displaced by the weight of the lever and its extension, a clamping device in the form of a frame is affixed to the framework of meter. The action of this clamp is brought about by the motion of the crank, and is so arranged that the ammeter hand is unclamped and free to move under the influence of the current while the pin on the crank is moving on the curved part of the lever. At this time the rod extension is at the zero position. Should no current be passing in the main coil, the ammeter hand will also be at its zero position, and when clamped will prevent the rocking lever from following the movement of the pin in the crank. It follows that as no movement of the lever takes place, there will be no motion of the wheel and attached counter. If current passes through the main coil then the hand will be deflected from the zero position when the clamping frame releases it, and will indicate the value of the current on the ammeter dial. After it has been again clamped, the lever will fall until the rod rests against the hand, and will remain in this position until the pin on the crank, in the course of its revolution, returns it to the zero position. Thus the distance through which the lever is allowed to oscillate is determined by the position or distance from zero of the ammeter hand. Each time while this lever is being returned to the zero position the pawl actuates the wheel, and the dials indicate a corresponding amount. This action is repeated every half minute, and the sum total of the integrations is registered on the counter in Board of Trade units.

The normal current required to operate the pendulum is about .18 of an ampere, and is, as before stated, intermittent in its action. The pendulum usually makes four or five complete oscillations without receiving an impulse.

The resistance wire for the pendulum circuit is wound on frames specially designed to give ample cooling surface.

Means are provided for locking the pendulum during transit, and a circular spirit level in conjunction with the two front adjustable feet provide the necessary levelling arrangements.

The next class of meter in the market are for continuous currents only, and are motor meters. The first, the Ferranti (Fig. 248), has a disc of mercury, which is contained in a magnet M, so that the magnetic flux passes vertically through the mercury disc. The consumer's current passes radially from the edge of the disc to the centre, with the effect of rotating the mercury at a speed proportional to the

Niagara Falls Electric Generating Plant

5000 horse-power dynamo alternating current, high pressure, driving by turbines. The largest water-power station in the world. Dynamos by Westinghouse Electric Company. Typical Water-Power Polyphase Generating Station

current. The magnet is one with plenty of iron in its circuit, so that its field is strong without approaching saturation.

The motion of the mercury is conveyed to the train of wheels by a spindle S carrying a fan F dipping under the mercury. This meter presented many difficulties to the inventor, but he finally overcame them after years of labour and much expense.

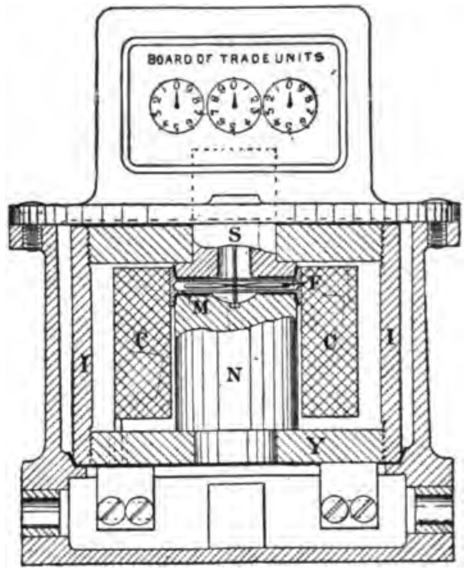


FIG. 248.—Ferranti Meter

In order to get rotation of the mercury, proportional to the amount of current passed, a satisfactory retardation had to be provided for the mercury, otherwise it would run away and give an incorrect registration.

To accomplish this the insulation covering the pole faces and forming the mercury bath is serrated with a number of radial grooves, which give the necessary retardation to obtain proportionality of rotation.

Another point of very great importance was the construction of the fan which conveys the motion of the mercury to the recording train of wheels. The fan has a difficult operation to perform, as it has to record accurately the rotation of the mercury, at the same time to offer very little attraction to the side of the bath, due to the surface tension in mercury. It has, therefore, gone through a number of modifications, and has now got the form which seems to comply with all these requirements. It consists of an aluminium fan, or rather a fan which is made up of two blades of aluminium and two blades of platinum, or else of four blades of non-magnetic steel, so arranged that the weight which prevents the fan and spindle from floating up is partly in the mercury and partly in the air. By carefully deciding these weights, the fan and spindle cause no weight on the jewel when the meter is at work; this is very vital to get full starting and to avoid wear of the pivots and jewels.

Another thing that was difficult to get in a satisfactory form was the mercury contact ring round about the bath. This used to be made of brass or copper, electro-plated with nickel in all earlier meters; but nickel-plating is porous, and the mercury soaked through it and ate away the brass or copper at the back, thus forming an amalgam.

The contact ring for the mercury, which was a great difficulty at first, has now been replaced by a steel ring, made sufficiently thin not to short circuit the lines of force which should pass through the bath.

All meters require some retarding force proportional to the torque. In the Ferranti meter the friction of the mercury and counter E.M.F. regulate the speed.

In the Chamberlain & Hookham meter, besides this friction and counter E.M.F., a magnetic brake is added. This is a great advantage, as by its means the retardation can be finely adjusted; and such adjustment is necessary in this meter, for the field is constant, being produced by a permanent magnet. In the Ferranti the field is electro-magnetic, and may be adjusted to regulate the speeds.

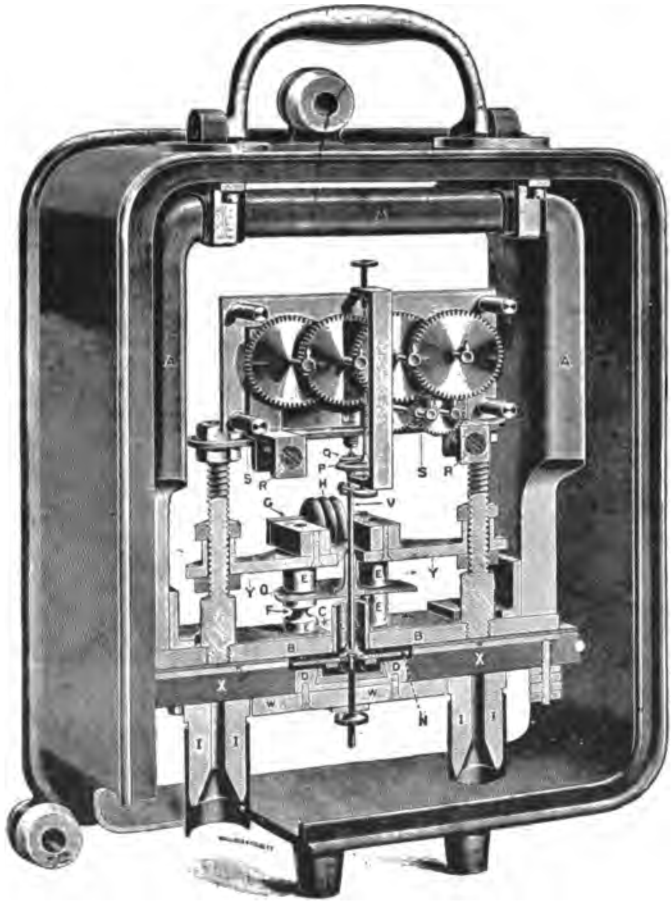


FIG. 249.—Chamberlain & Hookham Continuous Current Meter

The Chamberlain & Hookham continuous current meter is here illustrated (Fig. 249). Referring to the drawings, a single bent bar magnet A A of tungsten steel now replaces the dozen or so of straight magnets formerly contained in the brass tube. B B are plates of soft iron continuing the magnetic circuit towards the centre, where it is broken by the insertion of a brass piece, C. The lines of force pass downwards through the iron bridge-piece D D, being cut by the armature N twice, in opposite senses. They also pass upwards through the brake pole-pieces E E and the upper iron bridge-piece G. O is the brake-disc; H the correcting coils for fluid friction error; F the reduced saturated neck of one of the brake pole-pieces; K K insulated strips of copper, conducting the current from the terminals I I to the mercury cup L L, in which the armature is immersed and partially floated. The mercury is carefully insulated from the containing vessel except the ends of the copper strips K K.

The armature is slit radially for about one-third of its diameter all round, leaving a continuous area of copper in the centre.

The action of the meter is as follows: Owing to the great length of the magnet A A, an intense field is produced at B D, B D. The current flows across the diameter of the disc, being almost entirely confined (by the radial slits in the armature) to the area beneath the pole-pieces, which embrace each about one-third of the periphery of the disc. The armature thus cuts the field twice, instead of once, as in the 1892 pattern. Add to this the much greater intensity of the field, and also that the arrangement allows of the pole-pieces being placed further from the centre, and it will easily be understood that the torque is multiplied from five to seven times.

The power of the brake at E E, E E, is increased in the same proportion, so that the speed of the meter is not increased, The effect of the choking of the brake at F is in this meter very marked; it will be observed that the armature and brake field are magnetically in parallel, and consequently the armature field is a by-pass to that of the brake. Now, if there were no choking of the brake, the speed of the meter would increase with any falling off in the induction in the steel magnet. But it is obvious that, with the present arrangement, it would be possible, if the saturation of the necks were carried beyond a certain point, to produce the opposite effect. The brake remaining nearly constant, and the driving force of the motor falling off, the speed would *decrease* with a decrease of field. It is equally obvious that, between these extreme effects, an intermediate state is possible in which the speed of the motor is, through a considerable range of intensity, independent of the strength of the field. This point has been ascertained by experiment, and realised in practice, and in the present pattern it is possible to apply to the steel bar a demagnetising force of from 200 to 300 ampere-turns, without affecting the rate of the meter for practical purposes.

Mr. Hookham's meters can be arranged so as to record with the same accuracy and rotate at the same speed when running either backwards or forwards; or they can be arranged to run at a different speed when rotating in one direction than in the other.

This is accomplished without any mechanical movement in the meter, and is of great use in the charging of secondary batteries, the difference in rate of registration when running backwards or forwards being arranged so that, if the charging current runs the counter back to zero each time, a sufficient excess of charge over discharge has been put into the cells. In these motor meters the main current is passed through the rotating part, requiring no commutator, and the meters are only useful for continuous current; the ideal meter, however, must be useful on all circuits whatsoever.

The Thomson-Houston motor meter below described is suitable for all circuits. These meters require a regular dynamo commutator

with two brushes; this, with the pivot bearings, constitutes the chief frictional resistances, neglecting the commutator, which is perhaps the only drawback. This type of meter is theoretically the measurer of energy in any kind of circuit, and practically has been largely used. It is a watt-hour meter.

The meter consists ordinarily of a peculiarly constructed electric motor, having no iron in either armature or fields. The fields, which are composed of two coils of thick wire, one on either side of the armature, are connected in series with each other and with the circuit whose absorption of energy is to be measured. The armature is formed of a hollow frame wound with a set of coils of fine wire, on the Siemens drum principle, to which is attached a silver commutator, carried on the shaft near its upper bearing. Two light springs, with silver contact pieces, bear upon the commutator and constitute the brushes. The fine-wire armature is in series with a non-inductive high resistance, carried in the frame at the back of the meter, and forms a shunt to the main circuit, the current in it varying from instant to instant with the voltage.

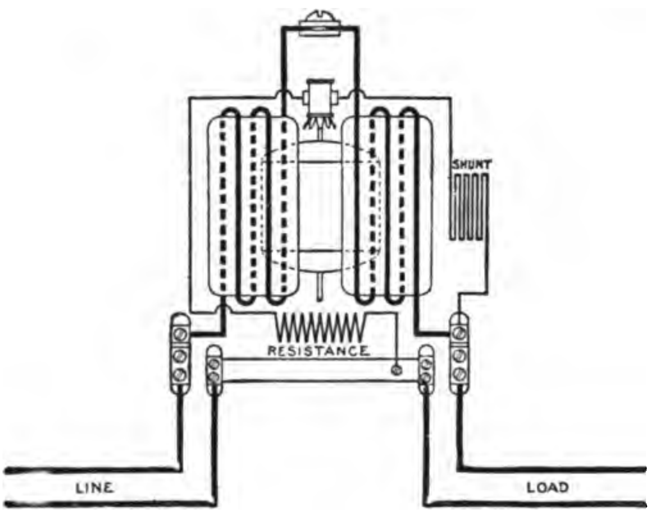


Fig. 250
Connections of Thomson Recording Watt-Meter for Two-Wire Circuits. 3 to 50 Amperes, 50 to 500 Volts

It will be evident that with such an instrument the torque at any given moment will be proportional to the amperes × volts = watts. To make the speed vary as the watts, it will be necessary to introduce some resistance to the rotation, which shall increase in direct proportion to the speed. This is accomplished in the most simple and satisfactory manner in the Thomson recording wattmeter by placing on the shaft a thin disc of copper, this disc rotating in a constant magnetic field between the poles of permanent magnets. These latter induce foucault or eddy currents in the disc, thus creating a drag on the motor. The ohmic resistance of the disc remaining constant, it is plain that, in a constant field, such as is produced by the permanent magnets, the E.M.F.—and, consequently, the current generated in the disc—will vary as the

speed; and the retardation, which is proportional to the current × field, will also vary directly as the speed. Thus a resistance has been provided which bears the same proportion to the speed as the torque of the motor bears to the watts; consequently, the resultant speed is directly proportional to the watts.

The principle of the instrument (friction errors being eliminated) is, therefore, such that a counting train geared to the motor shaft may be made to read directly in watt-hours.

1. It may be used on either continuous or alternating current, single or polyphase circuits, and is unaffected by changes in periodicity, power factor, or wave shape.

2. The readings are proportional throughout the entire range of the instrument.

3. It is accurate from the lowest to highest loads, and reads directly in B.O.T. units.

4. It is practically unaffected by changes in temperature or barometric pressure.

5. It is silent in operation.

Fig. 251 represents the ordinary two-wire meter. The disc and magnets are in the lower chamber; the upright spindle rests on a pivot; the main coils of thick wire stand on the first floor with a little drum armature between carried on the spindle; a worm and worm-wheel drives the recording train.

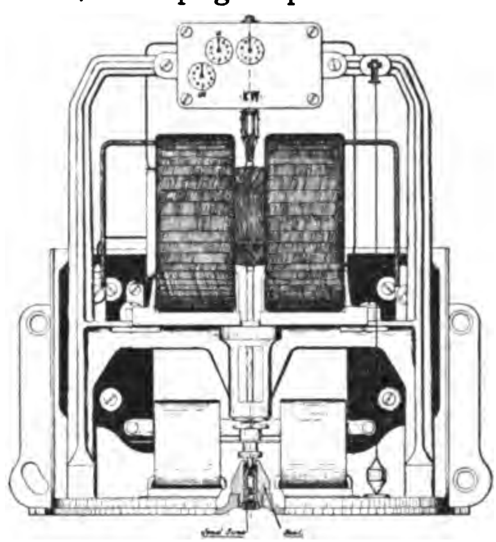


FIG. 251
Thomson-Houston Electricity Meter

The same company now supply a long-felt want for a portable meter suitable for electrically-driven vehicles (Fig. 252). The electrical and mechanical construction of the street railway meter is of that simplicity which ensures long life, accuracy, and little liability to get out of order. It is especially designed to operate under the conditions found in the electrical tramway service of to-day. The moving element is extremely light, which is an important feature in a meter for this service. It is also supplied with a special removable pivot for the lower bearing, which runs in a sapphire jewel, supported upon a spring designed to reduce to a minimum the liability of roughening the jewel due to excessive vibration.

The armature winding is of low resistance, measuring only about 30 ohms, and a high resistance (10,000 ohms) is in series with it.

This arrangement makes the drop across the armature circuit low, and greatly reduces the liability to spark at the brushes.

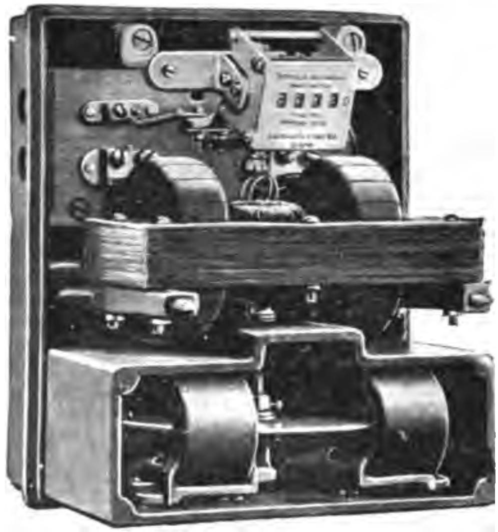


FIG. 252
Thomson-Houston Tramcar Electricity Meter

In electrical tramway service a meter is seldom called upon to work on light loads, and high accuracy on such loads is therefore unessential, and iron can be used in the fields, greatly increasing the torque and thereby allowing a heavy brush tension, which ensures perfect contact at all times. The use of iron also allows small drop across the armature, and the increased torque prevents the calibration from being affected by the varying vibration found in the service.

The meter is capable of recording with accuracy the rapidly varying load attending its use on tramcars. Special care has been exercised to rate these meters low enough to allow for accurate working on heavy over-loads, which often for short periods reach a value far in excess of the meter's rated capacity. Thus the meters are built to run on a 25 per cent. over-load for an almost indefinite period.

FIG. 253
Thomson-Houston O.K. Meter

The meter differs principally from the ordinary one in having a very small and light moving armature and a strong field provided by an iron core of laminated stampings.

The resistance of the armature circuit and shunt combined is 10,030 ohms, of which 30 ohms belong to the armature, so that the shunt circuit takes about 0.05 ampere only.

The O.K. meter of the Thomson-Houston Company (Fig. 253) is a motor meter suitable only for small loads up to 15 amperes, and only for continuous currents. It differs from other motor meters inasmuch as it operates on the natural principles of the electric motor without any brake

or retarding appliances or resistances. It is connected in the circuit as the shunted type of ammeters are connected, that is, across a resistance in series with the load, so that the P.D. on the armature is proportional to the load, and the armature, being in a constant permanent magnet field, rotates according to the laws of a shunt motor, the speed being proportional to the P.D. on the armature of an unloaded free motor. It requires a commutator and brushes. It measures only ampere-hours.

The armature or movable part is made as light as possible, so as to reduce to a minimum the wear on the bearing jewel and pivot. The meter is practically independent of temperature variation, thus ensuring the accuracy of the meter regardless of variations of temperature occurring naturally.

The meter is entirely enclosed in a dust-proof cover, and all parts are protected from mechanical injury. The cover is arranged in such a manner as to permit of connections being made and sealed without exposing the measuring mechanism. All parts are properly insulated, so that the danger from an earth is entirely eliminated.

There is approximately one-half a volt drop due to the instrument resistance with full load, and so the loss of energy from this source is negligible.

The motor starts with 1 per cent. of the full load current, thus ensuring a high degree of accuracy on the smallest loads (one 5 c.p. lamp) which the instrument is expected to record.

The O.K. meter is perhaps the simplest continuous-current motor meter for small loads.

The small consumer, however, has not yet been supplied with a meter at a cost proportionate to his consumption. Large meters, costing from 50s. to 100s., are not too costly on a circuit consuming hundreds of units per annum, but cost too much for smaller consumers; hence the temptation to inventors to introduce cheap electrolytic meters without mechanism to meet the small consumer. Some of them have met with success to an extent, but there is a rooted prejudice against the use of acids and solutions in house meters.

No doubt much simpler and cheaper meters shall yet be brought out. As time goes on the problems are gradually solved and difficulties overcome—the natural progress of evolution.

The evolution of the meter has been revealed in the various claims made by different inventors. The inventors themselves knew, no doubt, exactly wherein their own improvements lay and of what they consisted, but their patent agents evidently did not, for the specifications describe a great deal of old and well-known devices, with a great deal of useless illustrations. In one specification the only new device is a commutator, but the drawings consist

of three sheets illustrating two meters in every detail complete, the real improvement being entirely hidden among the rubbish.

Messrs. Ayrton & Perry published the earliest descriptions of the principles of the clock meters and of the mercury meters with retarding brake, afterwards worked out and put into practice by Hookham, and Aron, and Ferranti; and the motor generator meter was undoubtedly first described by Siemens, and afterwards worked out by E. Thomson in his ironless watt-hour meter with magnetic brake.

The difficulties are great in the way of making an ideal meter, not so much in the way of securing great accuracy as in securing thorough reliability for a lengthened period of use without undue cost in supervision. A rather inefficient and moderately incorrect meter, which can be depended upon to remain constant in its work, is much to be preferred to the refinements of the instrument-maker, giving extraordinarily high efficiency and accuracy which cannot be depended upon for a month at a time. The forces at work in an electricity supply meter are necessarily very minute, and it is simply a question as to how far these can be reduced without running the risk of a total stoppage from very slight and uncertain causes.

All moving meters have mechanical friction which must be overcome by the motive electrical forces, and in order to overcome these frictional resistances an initial electric field is provided, by using a "starting coil" in the shunt circuit acting in conjunction with the other field coils. In this way the meter is just on the point of moving when no lamps are in circuit, so that, when one small lamp is switched on it readily moves. This device is used in the Thomson-Houston meters and in some others. Some recently invented meters, particulars of which cannot be obtained at present, shall be referred to later on.

END OF VOL. I.

Printed by BALLANTYNE, HANSON & Co.
Edinburgh & London